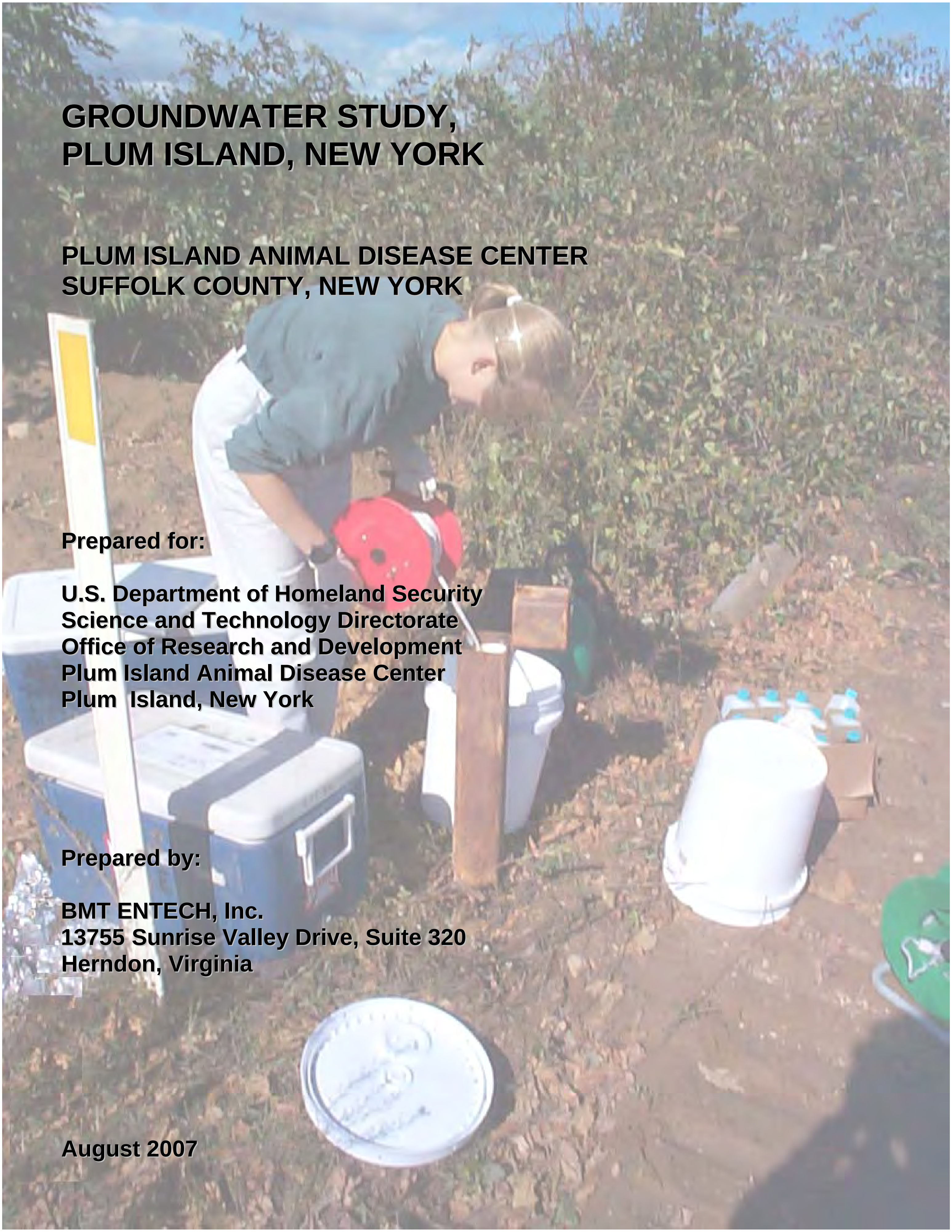

GROUNDWATER STUDY, PLUM ISLAND, NEW YORK

PLUM ISLAND ANIMAL DISEASE CENTER
SUFFOLK COUNTY, NEW YORK

Prepared for:

U.S. Department of Homeland Security
Science and Technology Directorate
Office of Research and Development
Plum Island Animal Disease Center
Plum Island, New York

Prepared by:

BMT ENTECH, Inc.
13755 Sunrise Valley Drive, Suite 320
Herndon, Virginia

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DEFINITIONS

Cone of depression: The depression of head around a pumping well caused by the withdrawal of water.

Drawdown: The reduction in head at a point caused by the withdrawal of water from an aquifer.

Head (total head): The height above a datum plane of a column of water. In a groundwater system, it is composed of elevation head and pressure head.

Hydraulic conductivity: The capacity of a rock to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Specific Yield: The ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock.

Storativity (storage coefficient): The volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance.

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.

(Heath, 1983)

EXECUTIVE SUMMARY

ENTECH, Incorporated, the progenitor of BMT Entech, Inc. (Entech), was requested to update the Plum Island Animal Disease Center's (PIADC's) 1983 groundwater survey. The update was required to provide current information regarding the availability, condition, and exploitation limits of potable water resources from the island's sole source aquifer. The investigation (Study) subsequently undertaken by Entech in the fall of 1999 was conducted as part of a larger Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigation into past waste management practices by the facility. A draft report documenting the findings and recommendations of this Study was initially produced in September 2000 for review and consideration by PIADC. References in the report to "current" conditions or proposed plans reflect the state or condition of particular features or activities in 1999. Finalization of this report did not occur until August 2007. Minor changes to the language of the draft text have been incorporated into this final report to reflect the passage of time since the draft was developed and distributed. The Study's major findings, conclusions, and recommendations are summarized below.

Physical Characteristics of Plum Island

Literature searches were combined with the results of environmental media sampling to characterize the general physiography, topography, geology and hydrogeology of Plum Island.

Plum Island consists of gently sloping terrain covered with scrub brush and trees. The southernmost portion of the island is comprised primarily of sand dunes less than 10 feet in height and sandy beaches. The maximum elevation is approximately 101 feet above mean sea level on the north-central portion of Plum Island. Approximately 54 acres of wetlands are situated on the western end of the island. Surface water runoff is minimal due to the high permeability of sandy soils. No streams or rivers are present on the island, and no surface water bodies are used for potable water.

Crystalline bedrock probably occurs at a depth of 600-700 feet below ground surface. The bedrock is overlain by semi-consolidated and unconsolidated sediments. The upper 200 to 300 feet of the island consists of glacial deposits of sand and gravel. A fresh water lens extends to an approximate depth of 100 feet in the center of the island.

Water Budget Analysis

Entech performed a water budget analysis based upon historical records and the evaluation of current (1999) site conditions. The purpose of the analysis was to predict the maximum amount of groundwater that may be sustainably withdrawn without adversely impacting water quality or availability. This figure is known as the "safe yield."

A water budget analysis never produces a single value for safe yield. Due to the large number of variables involved and the fact that impacts may be economics-related, wildlife-related or even political "captive", the resulting safe yield is best expressed as a range of values. In this Study, ranges were developed using two methods. These ranges were refined, based on professional judgement, to produce a single "target" value for safe yield. The outcome of this analysis yields the following three key recommendations:

- A target safe yield for PIADC of 55,000,000 gallons per year (gpy) or approximately 150,000 gallons per day (gpd) should not be exceeded.

- Three sentry wells should be installed to monitor the saltwater-fresh water interface below the island.

- Construction of impermeable surface barriers, such as parking lots, should be avoided in the areas upgradient from the well fields. Such development inhibits the infiltration of meteoric water, and reduces recharge to the aquifer.

Aquifer Testing

Entech conducted 24-hour aquifer pumping tests at each of PIADC's two well fields. The purpose of these tests was to characterize the hydraulic properties of the sole source upper glacial aquifer beneath Plum Island, assess radii of pumping influences, and determine whether either of the two well fields might potentially be affected by groundwater contamination originating from waste management sites located nearby. These sites are generally referred to as Waste Management Areas (WMAs) or Areas of Potential Concern (AOPCs).

The resulting pump test data were indicative of a highly transmissive aquifer (88,000 to 122,000 gallons per day per foot [gpd/ft]). Average hydraulic conductivities (1,100 to 1,530 gpd/ft^2) were similar to those values expected in a coarse sandy aquifer (Heath, 1983). Average storativity values (4×10^{-3} to 1×10^{-2}) were somewhat lower than expected. This may be due to the presence of fine sand in the pumping zones.

Distance-drawdown analyses based on estimating the radius of the cone of depression after 24 hours of pumping, were performed for each of the well fields. The radius at the Deep Well Field is estimated to be 170 feet at a pumping rate of 83 gpm. At the Shallow Well Field, where smaller (40 gpm) pumps are currently in use, the pumping radius is estimated at 70 feet.

Groundwater seepage velocities and travel times along three flow paths were estimated based upon the pumping test results. The travel time calculations suggest that the fresh water lens beneath Plum Island flushes completely within approximately 20 years.

Groundwater Use at PIADC

In 1999, twelve functioning wells served all of PIADC's water supply needs. Excess pumped groundwater was stored in a 200,000 gallon water tower.

PIADC production wells are located in two fields. Wells 1-10 comprise the Shallow Well Field, and are, on average, about 30 feet deep. Wells 11-14 comprise the Deep Well Field and average about 60 feet in depth.

Wells 1-10 contain 25-40 gallons per minute (gpm) pumps at the time the Study was conducted. Current (1999) plans called for all 14 wells to contain these pumps by December 2000. Wells 13 and 14 had higher capacity (80-100 gpm) pumps in 1999.

Individual pumps were operated from the pump houses at each field. It was necessary to activate and deactivate each pump manually at that time. Plans called for the automation of the pumps by the end of 2000.

All groundwater withdrawn from the supply wells pass through the treatment system located at Building 59. Lime and chlorine are added, and the water is passed directly into the distribution system. Only excess water that had been withdrawn but not used during the course of a day was sent to the water storage tower.

Treated water is distributed about the island through a variety of 4" cement and 8", 10" and 12" cast iron pipes. Many of the lines on the northeastern portion of the island have been removed from service in the past 10 to 15 years.

Future PIADC Water Use

At the time the Study was initiated, plans for expanding the research facilities at Plum Island to Bio-Safety Level 4 (BSL-4) status were under consideration. Since that time, the BSL-4 concept has been abandoned, but upgrades to the existing BSL-3 facility infrastructure are anticipated to begin in 2008. These upgrades are intended to extend the operational life of PIADC until a new replacement animal disease center is constructed and "on-line". This new facility, however, is not expected to be constructed on Plum Island.

In light of the anticipated growth of PIADC, USDA-ARS requested that development scenarios be created to gauge the impact construction would have, regardless of BSL "rating" or status, on existing potable water resources. The basic assumptions provided by USDA-ARS for these scenario exercises called for a 50% expansion of PIADC's physical plant and a 50% increase in water needs (Payne, 2000). Recent water withdrawals have averaged 70,000 gpd. An increase of 50% means an average water use of 105,000 gpd after expansion. A modified value of 110,000 gpd was used for daily expanded use calculations. This is approximately equal to a 50% increase over the 1998 daily average and is well below the target safe yield of 150,000 gpd .

Three different scenarios were evaluated with regard to future water use. The analysis of these scenarios concluded that the expanded water use of 110,000 gpd can easily be met with the existing well and pump network. In fact, this rate has been achieved in the past. Water use during the period of 1978 to 1982 averaged 102,000 gpd to 110,000 gpd. Again, this is well below the target safe yield of 150,000 gpd.

Increasing Firefighting Capacity

Intense firefighting activities can empty PIADC's 200,000 gallon water storage tank in under two hours, and the tank is unlikely to be full in time of need. Five scenarios were developed and analyzed to identify ways to increase firefighting capacity. Analyses of these varied scenarios resulted in the conclusion that significant increases in firefighting capacity could be achieved through use of the Army-era reservoir and/or PIADC's existing saltwater pump system. Bringing the existing reservoir and associated fire pump online, or installing a new 1,000,000 gallon reservoir and pump, would provide over six hours of continuous firefighting. A combination of the reservoir and the existing saltwater pumps might be ideal, with the saltwater system being a worst case backup. In any case, changes would need to be made to the current water delivery system. If the existing reservoir were to be used, it would need to be renovated to potable standards, connected to a completely separate system, or only used in emergencies.

Wellhead Protection Assessment

The 1986 Amendments to the Safe Drinking Water Act established the Federal Wellhead Protection Program. The 1996 Amendments to the Safe Drinking Water Act placed even greater emphasis on prevention by creating the Source Water Protection Program. Entech undertook an assessment at Plum Island that loosely conformed with the methodology set forth in the EPA's State Source Water Assessment and Protection Programs - Final Guidance (1997). A Wellhead Protection Area (WHPA) was established, potential contamination sources were identified, and the susceptibility of the WHPA to contamination was assessed.

One WHPA was established covering both wellfields at PIADC. The WHPA consists of two Zones of Transport (ZOTs). The purpose of establishing ZOTs is to identify areas where the use of hazardous materials should be restricted, in order to prevent potential contamination of the potable groundwater supply. The two ZOTs recommended at Plum Island are further described/defined below:

Zone of Transport 1: No use, handling or storage of hazardous materials. ZOT 1 extends 100 feet downgradient from the farthest downgradient well in each field, and upgradient to the groundwater divides A significant chemical release in these areas would be a serious threat to the quality of the water being withdrawn from the well fields. The installation of any underground storage tanks (USTs) should be avoided. Aboveground tanks (ASTs) should also be avoided. The goal of ZOT 1 is to to create an environment of extremely low threat in the immediate vicinity of the supply wells. Other practices that should be avoided in this area are the application of sewage treatment sludges, the use of pesticides and the through-traffic of hazardous materials. Drinking water treatment processes at the Building 59 area must be exempted from this rule. However, these processes should be closely monitored for any sign of potential contaminant release.

Zone of Transport 2: Restricted use of hazardous materials. ZOT 2 extends 100 feet beyond the extent of ZOT 1. A very significant chemical release in ZOT 2 could seriously impact the well fields. Groundwater travel times from this zone to the water supply wells are estimated to be 30 days or more. However, the sandy soils of Plum Island would be unlikely to promote considerable natural degradation of a contaminant. The restrictions for use of this area should be similar in kind, but not degree, to those for ZOT 1. For instance, ASTs might be permitted in this area if they included proper secondary containment structures. Also, vehicles carrying significant quantities of hazardous materials might be routed around ZOT 1, and through ZOT 2.

If facility expansion results in an increase in water use of 50% over current levels, no additional wells will be necessary. However, greater expansion may require the installation of additional wells. Any new wells should be placed in the central portion of the island, where the freshwater lens is thickest. This means expanding the Deep Well Field to the northeast or to the southwest. The WHPA already covers the area between the existing well fields, southwest of the Deep Well Field, so this would be the logical place to site new wells.

Care should be taken to limit well interference when siting new wells. Wells should be aligned with recharge features (the nearest groundwater divide) and spaced appropriately based on their predicted pumping radii of influence. The area between the Shallow Well Field and the central groundwater divide should be avoided. Wells placed in this area would intercept recharge water needed by the shallow wells.

Summary of Drinking Water Regulations

The Suffolk County Department of Health Services (SCDHS) has classified PIADC as a “Non-transient Non-community Public Water Supplier”. As a result, PIADC is required to meet the monitoring and reporting requirements of the Federal Safe Drinking Water Act. The required water quality parameters and sampling schedule established by the SCDHS are presented in Table 9.1. All analytical results for sampling conducted in 1999 are provided in Appendix J.

1. INTRODUCTION

This Groundwater Study was conducted in the fall of 1999[1] and was produced as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigation of the Plum Island Animal Disease Center (PIADC), Plum Island, Suffolk County, New York. The United States Department of Agriculture - Agriculture Research Service (USDA-ARS) who owned and operated PIADC from the mid-1950s to 2003, conceived of a general plan for identifying and evaluating known and suspected waste disposal sites present on Plum Island in the late 1990s. That plan, which was based on the principles of EPA's CERCLA investigation program, was also intended to evaluate and employ remedies, as required, to address hazards uncovered by those investigations in order to protect the public health, welfare, and the environment. To implement this plan, the USDA-ARS entered into an Interagency Agreement (IAG No. 1910-A177-A1) with the Department of Energy (DOE) to provide the technical assistance necessary to initiate this process. Lockheed Martin Energy Systems, Inc. (LMES) Advanced Infrastructure Management Technology (AIMTECH), a DOE contractor, was assigned the task of administrating and managing the IAG on behalf of DOE. Under AIMTECH's General Order Contract No. 95B-99298C, CDM Federal Programs Corporation (CDM) and ENTECH, Incorporated, the progenitor of BMT Entech, Inc. (Entech), were selected to provide the technical assistance required to undertake the CERCLA-oriented investigations requested by USDA-ARS. These technical activities were subsequently identified by PIADC as its CERCLA Program (Program). The Groundwater Study (Study) presented in the balance of this report represents one element of the larger Program structure.

1.1 Purpose of Groundwater Study

Entech was assigned responsibility by AIMTECH for undertaking an "update" of an existing 1983 groundwater survey of Plum Island. That survey focused on the possibility of artificially recharging Plum Island's sole source aquifer with treated wastewater (ERM, 1983). The rate of water consumption at PIADC was increasing in the mid-1980's, and this trend was expected to continue over time. As a result, USDA-ARS wanted to investigate and evaluate the technical, environmental, and economic feasibility of using treated wastewater from its on-site treatment plant would insure an adequate potable water supply for future use.

The Study undertaken by Entech was conducted in overlapping phases. Phase I consisted of the identification, assembly, and interpretation of available information such as USGS technical papers, New

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1 This report presents the findings and recommendations of the updated Groundwater Study (Study) that was conducted in the fall of 1999. A draft report documenting the outcome of this Study was produced in September 2000 for review and consideration by PIADC. References to "current" conditions or proposed actions reflect the state or condition of particular features or activities at PIADC in 1999. Finalization of this report did not occur until August 2007; minor changes to the language of the draft text have been incorporated to reflect the passage of time since that document was developed.

York State Geological Survey (NYSGS) reports and files, drilling logs from the existing wellfields, and other site-specific sources. Phase II consisted of implementing two 24-hour aquifer pump tests to determine the hydraulic characteristics of the aquifer. Phase II concluded with a letter report that summarized pumping test findings (Appendix A). Graphs of test results are presented in Appendix B. Phase III consisted of the evaluation of data and the development of groundwater use scenarios and a wellhead protection program.

1.2 Report Organization

The following is a brief outline of the sectional elements of this report:

- **SECTION 1 - INTRODUCTION:** Presents the Study's objectives.

- **SECTION 2 - PHYSICAL CHARACTERISTICS OF PLUM ISLAND:** Provides an overview of the physiography, topography, geology and hydrogeology of the island.

- **SECTION 3 - WATER BUDGET ANALYSIS:** Evaluates groundwater resources at Plum Island and provides recommendations for addressing possible facility expansion requirements.

- **SECTION 4 - AQUIFER TESTING:** Presents the methodology, results, and interpretation of data associated with the two 24-hour aquifer tests.

- **SECTION 5 - CURRENT PIADC GROUNDWATER USE:** Describes the current (1999) infrastructure of PIADC's potable water systems and an overview of groundwater usage.

- **SECTION 6 - FUTURE PIADC WATER USE:** Analyzes methods for withdrawing groundwater in sufficient quantities to support facility expansion.

- **SECTION 7 - INCREASING FIREFIGHTING CAPACITY:** Analyzes methods for providing additional water supplies and storage alternatives to support firefighting requirements.

- **SECTION 8 - WELLHEAD PROTECTION ASSESSMENT:** Presents rationale behind establishing Wellhead Protection Areas on Plum Island.

- **SECTION 9 - SUMMARY OF DRINKING WATER REGULATIONS:** Presents PIADC's drinking water sampling and analytical requirements.

- **SECTION 10 - CONCLUSIONS AND RECOMMENDATIONS:** Summarizes the Study and presents recommendations regarding future groundwater monitoring and use.

2. PHYSICAL CHARACTERISTICS OF PLUM ISLAND

This section presents general physiographic, topographic, geologic and hydrogeologic information on Plum Island. It draws upon technical documents and observations from the larger CERCLA investigation of PIADC.

2.1 Location

PIADC is located on Plum Island in the Township of Southold, Suffolk County, Long Island, New York, approximately 1.5 miles from the eastern end of the Northern Fork of Long Island, about 12 miles southwest of New London, Connecticut. Plum Island is irregularly-shaped and totals 840 acres in size. The island is about 2.9 miles long and ranges from approximately 0.2 mile wide at its eastern end to 1.7 miles wide at its western end. The general vicinity of Plum Island is shown in the northeast portion of Figure 2.1. Figure 2.2 depicts the island in more detail.

Plum Gut, a strait 1.5 miles wide, separates Plum Island from Long Island. Other surface water bodies surrounding the island include Long Island Sound to the north, Block Island Sound to the east, and Gardiners Bay to the south. Access to Plum Island is restricted and gained solely by helicopter or government-owned and operated ferry service between the island and Orient Point, New York, and Old Saybrook, Connecticut.

2.2 Topography and Surface Water

Plum Island consists of gently sloping terrain covered with scrub brush and trees. The southernmost portion of the island is comprised primarily of sand dunes less than 10 feet in height and sandy beaches. The maximum elevation is approximately 101 feet above mean sea level on the north-central portion of Plum Island. Approximately 54 acres of wetlands are situated on the western end of the island. Surface water runoff is minimal due to the high permeability of sandy soils. No streams or rivers are present on the island, and no surface water bodies are used for potable water. A topographic map of the island is presented as Figure 2.3.

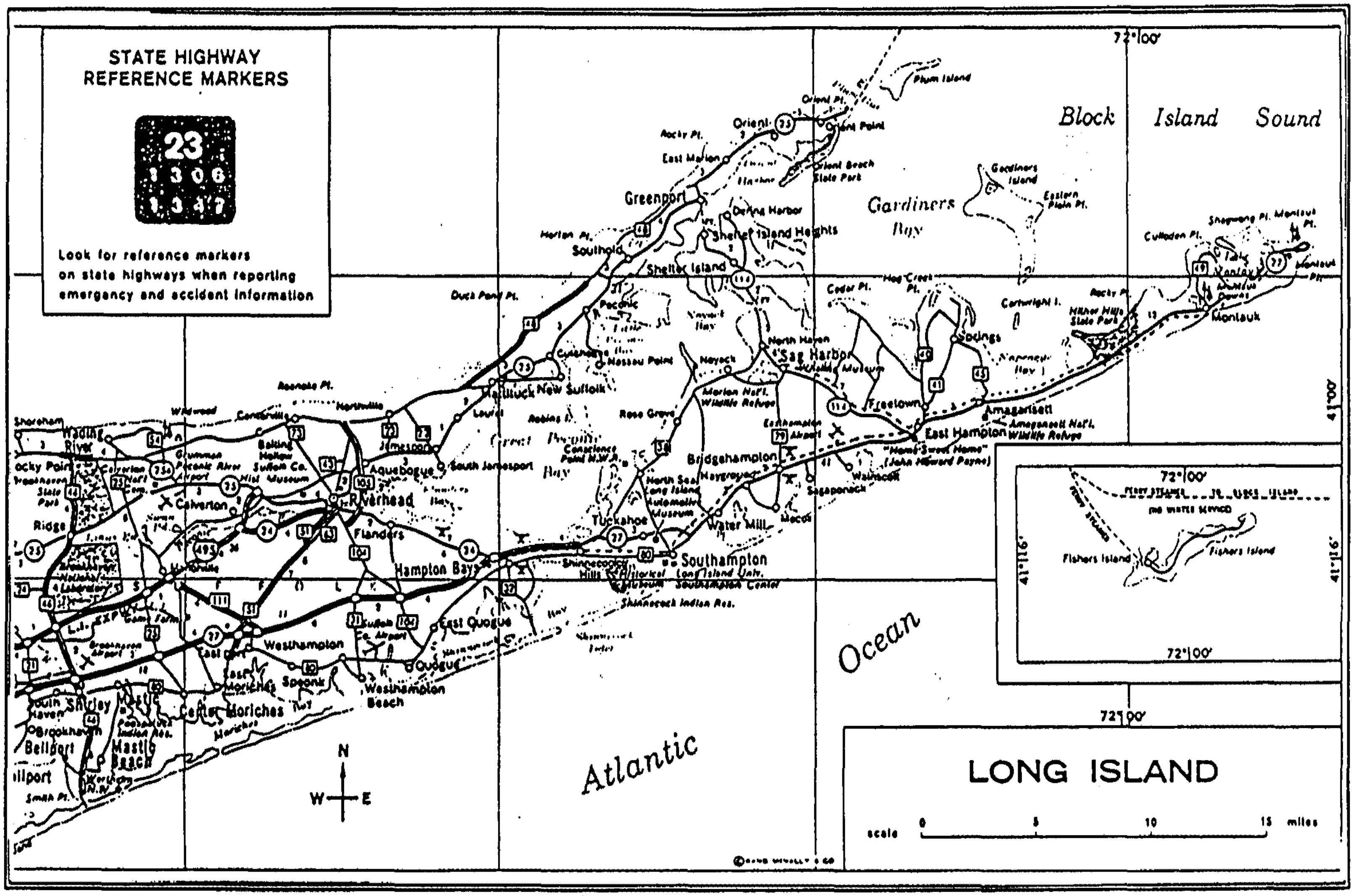


Figure 2.1 Plum Island Vicinity Map

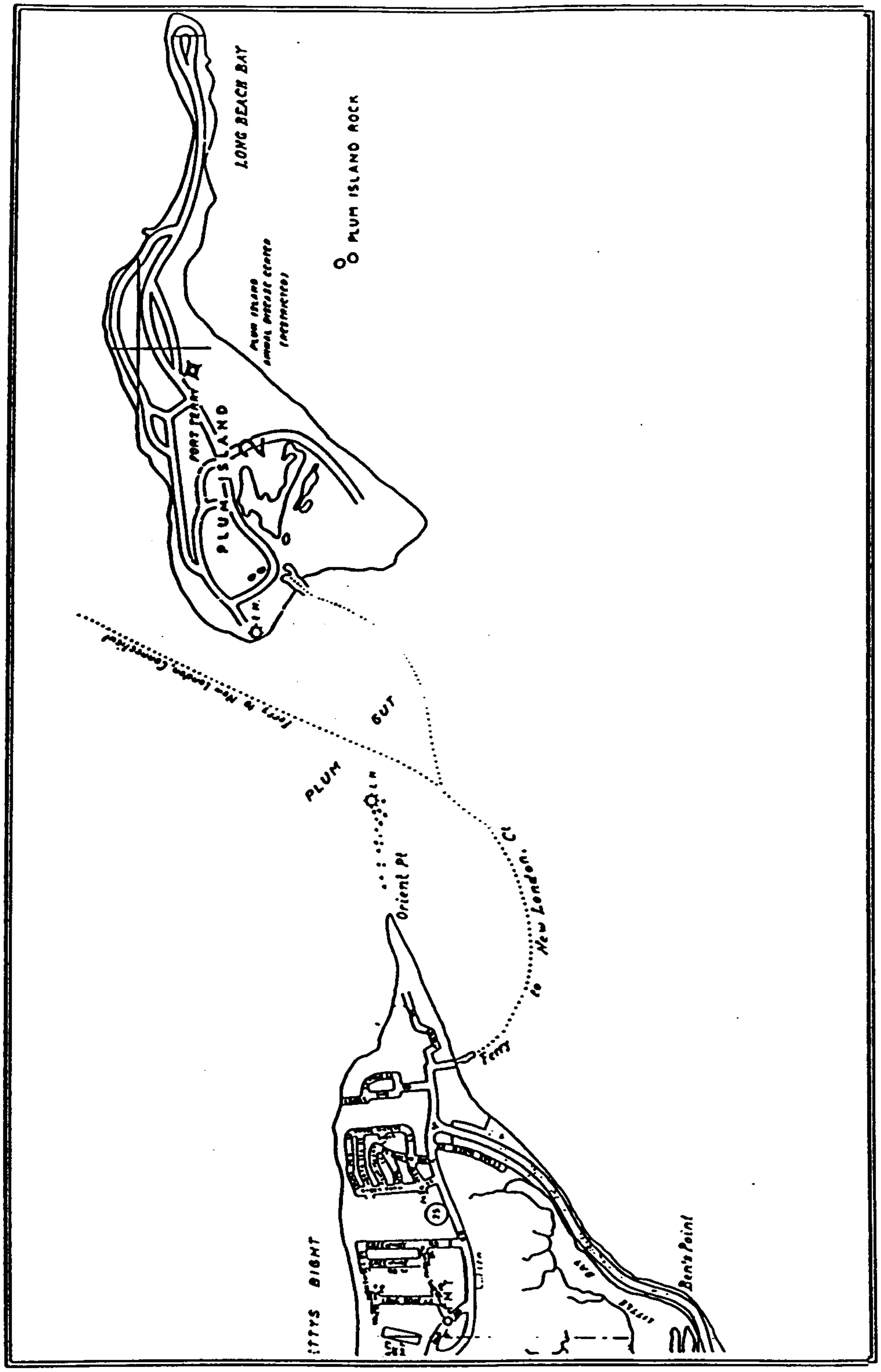


Figure 2.2 Plum Island Site Location Map

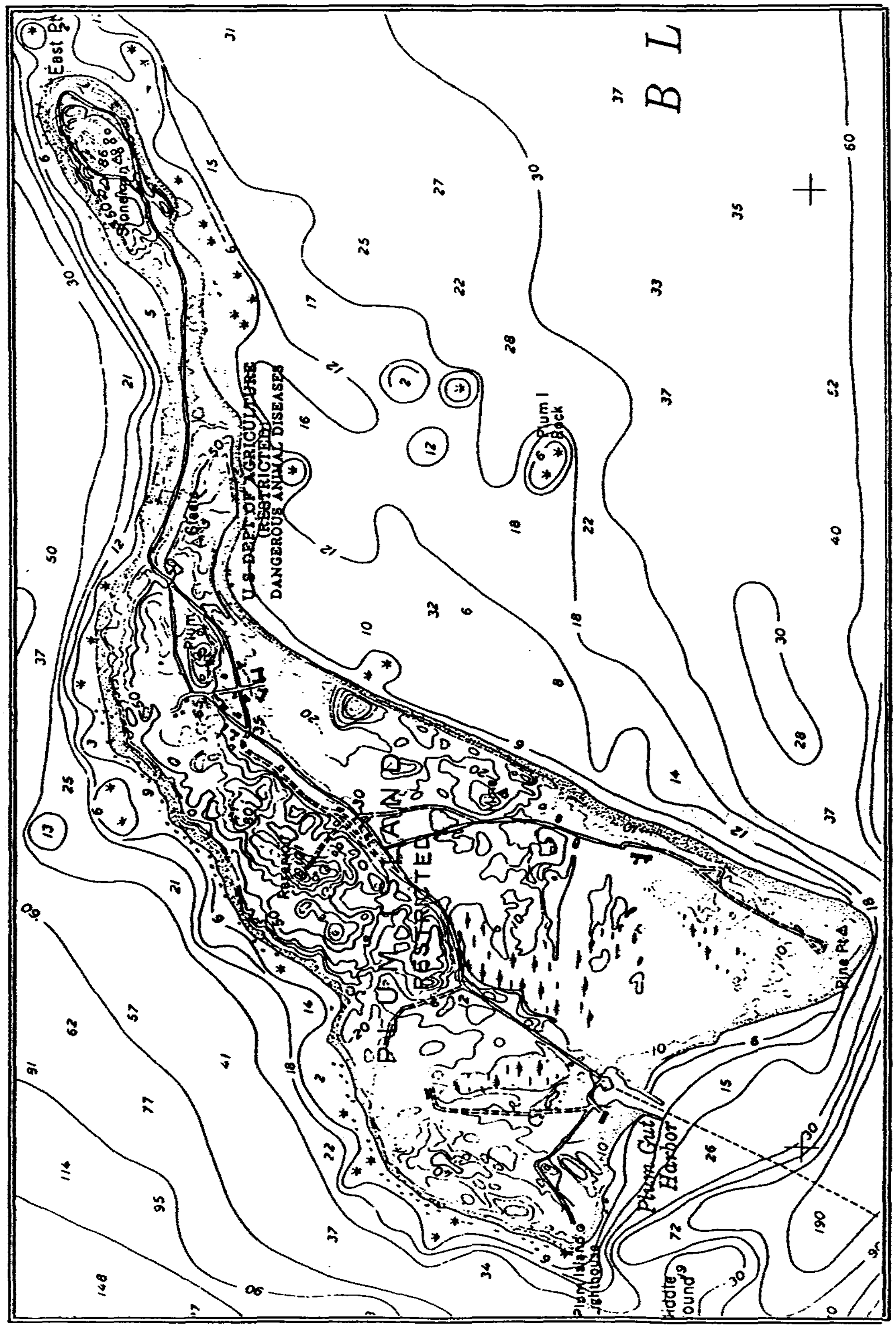


Figure 2.3 Plum Island Topography

2.3 Geology and Hydrogeology

The following descriptions refer to Figures 2.4 and 2.5. Figure 2.4 presents a plan view of the surficial geology of Plum Island. Figure 2.5 is a cross-section across the island.

A Precambrian crystalline basement probably occurs at a depth of 600-700 feet below Plum Island. The bedrock is overlain by semi-consolidated and unconsolidated sediments of Cretaceous and Quaternary age. Directly atop the bedrock is the Raritan Formation. The sandy portions of the Raritan make an excellent aquifer on Long Island, but undoubtedly contain brackish or salt water beneath Plum Island. Above the Raritan lie the post-Raritan Cretaceous deposits of sand, gravel, silt and clay. Several post-Raritan units make good aquifers on Long Island, but also probably contain brackish or salt water beneath Plum Island.

The upper 200 to 300 feet of the island consists of Pleistocene glacial deposits. Sand and gravel predominate, with the entire thickness being saturated. A fresh water lens extends to an approximate depth of 100 feet in the center of the island. Crandell (1962) estimated this depth using the Ghyben-Herzberg method of multiplying the thickness of a freshwater lens above sea level by 40 to obtain its thickness below sea level. The maximum elevation of the water table is approximately 2.5 feet above sea level in the center of Plum Island.

During a period of ice retreat and stagnation, till material that made up the central portion of the island was scoured out and filled with outwash material. All of the water supply wells at Plum Island are screened in these outwash sands and gravels (Crandell, 1962).

Groundwater occurs on Plum Island within the sand and gravel of the Upper Pleistocene glacial deposits. The groundwater surface mimics the island's topography and flows radially from the areas of high topography toward the shoreline. The shape of the unconfined aquifer is believed to be that of an irregular lens. The depth to groundwater on the island ranges from 0 to more than 75 feet below ground surface (bgs). The upper or "potentiometric" surface of the aquifer is represented as contour lines shown in Figure 2.6. It should be noted that these contour lines are relative to mean sea level.

The fresh water aquifer underlying the island is separated from the aquifer underlying Long Island, the nearest point of land, by a strait known as Plum Gut. The unconfined aquifer is recharged solely by precipitation, which averages approximately 45 inches per year. Much of the precipitation infiltrates through the island's highly permeable soils; however, runoff is estimated at about 15 percent of annual precipitation.

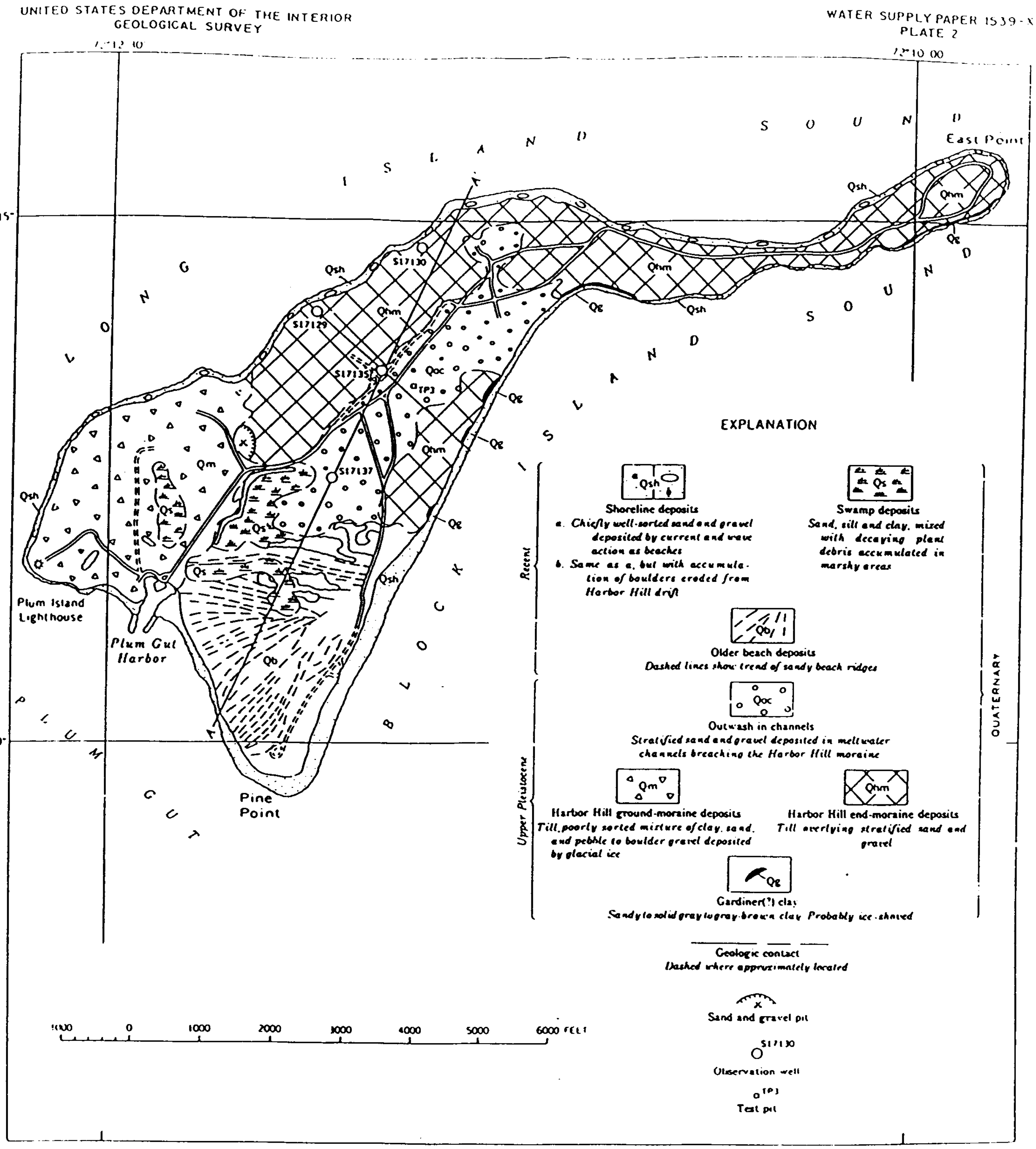


Figure: 2.4 Surficial Geologic Map of Plum Island

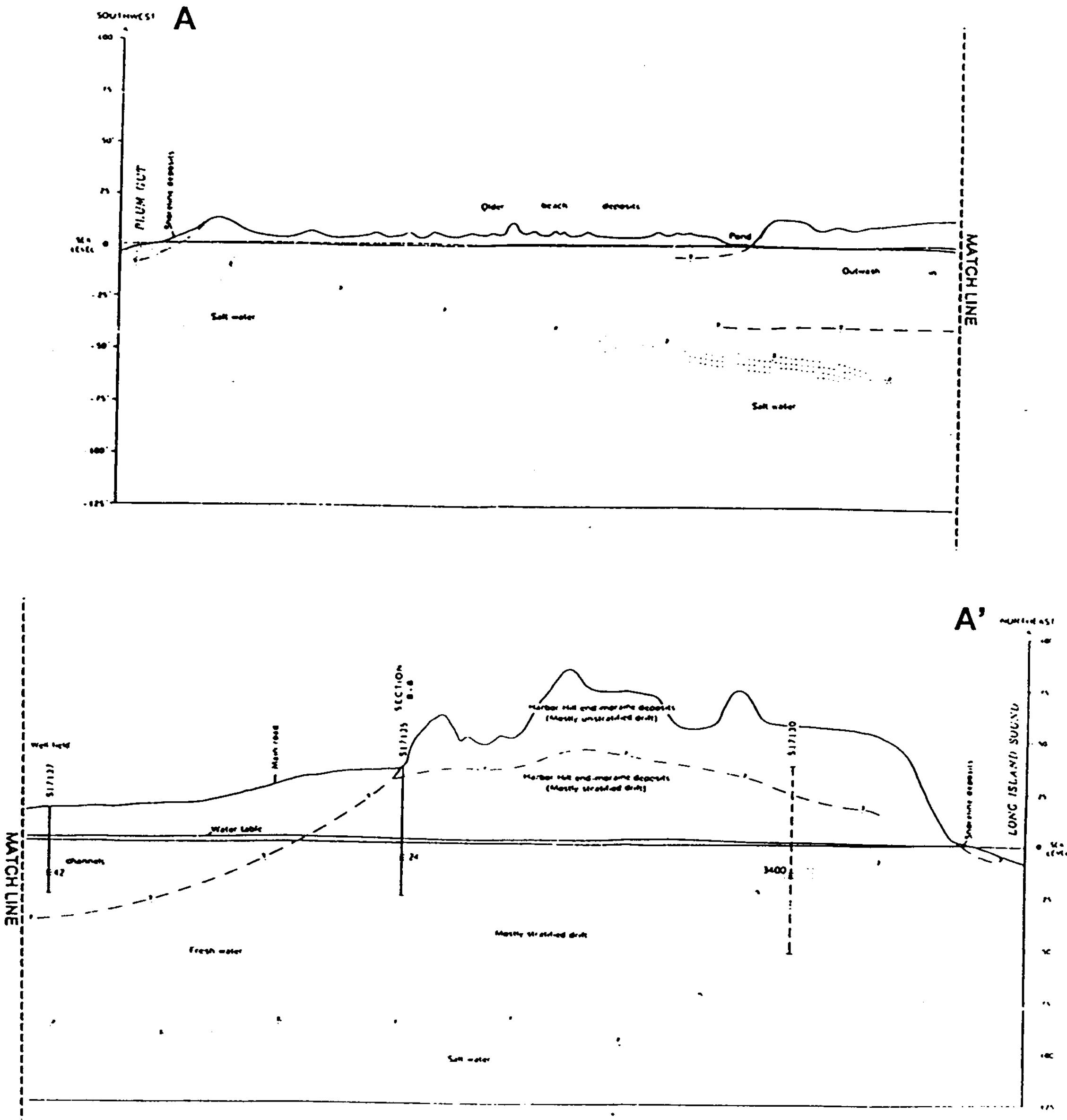


Figure: 2.5 Geologic Cross Section of Plum Island

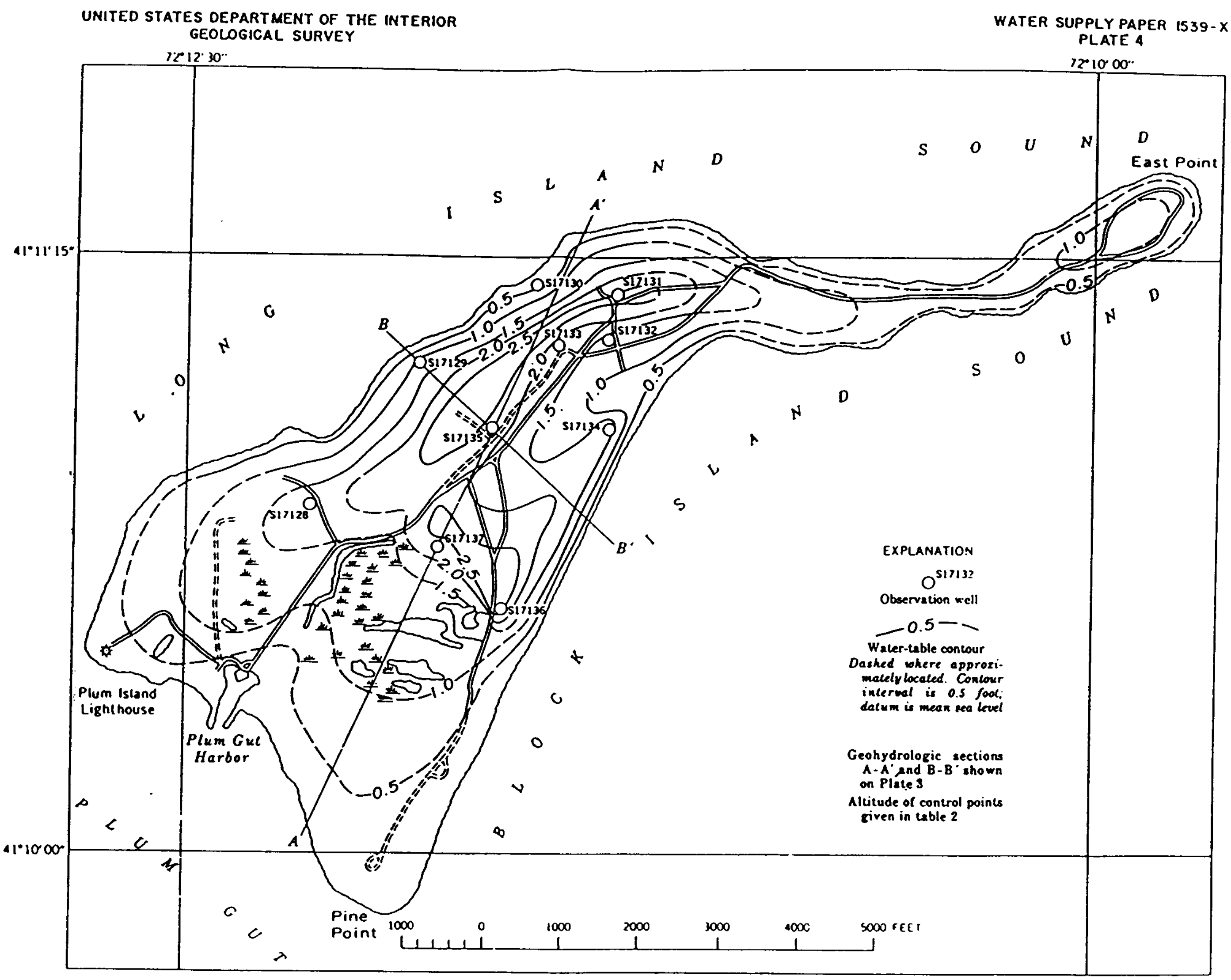


Figure: 2.6 Potentiometric Surface Map of Plum Island

Groundwater is the only source of potable drinking water on Plum Island. In 1999, fourteen (14) federally-owned shallow groundwater supply wells were actively used to draw water from the unconfined aquifer. These wells supply all potable drinking water for PIADC's employees and visitors. Ten (10) of the supply wells, all about 25 feet deep and spaced 35 feet apart, are located near Building 59 (Well Pumphouse). The remaining 4 wells, all about 60 feet deep, are located adjacent to Building 115 (Well and Fire Pumphouse) (Figure 2.7).

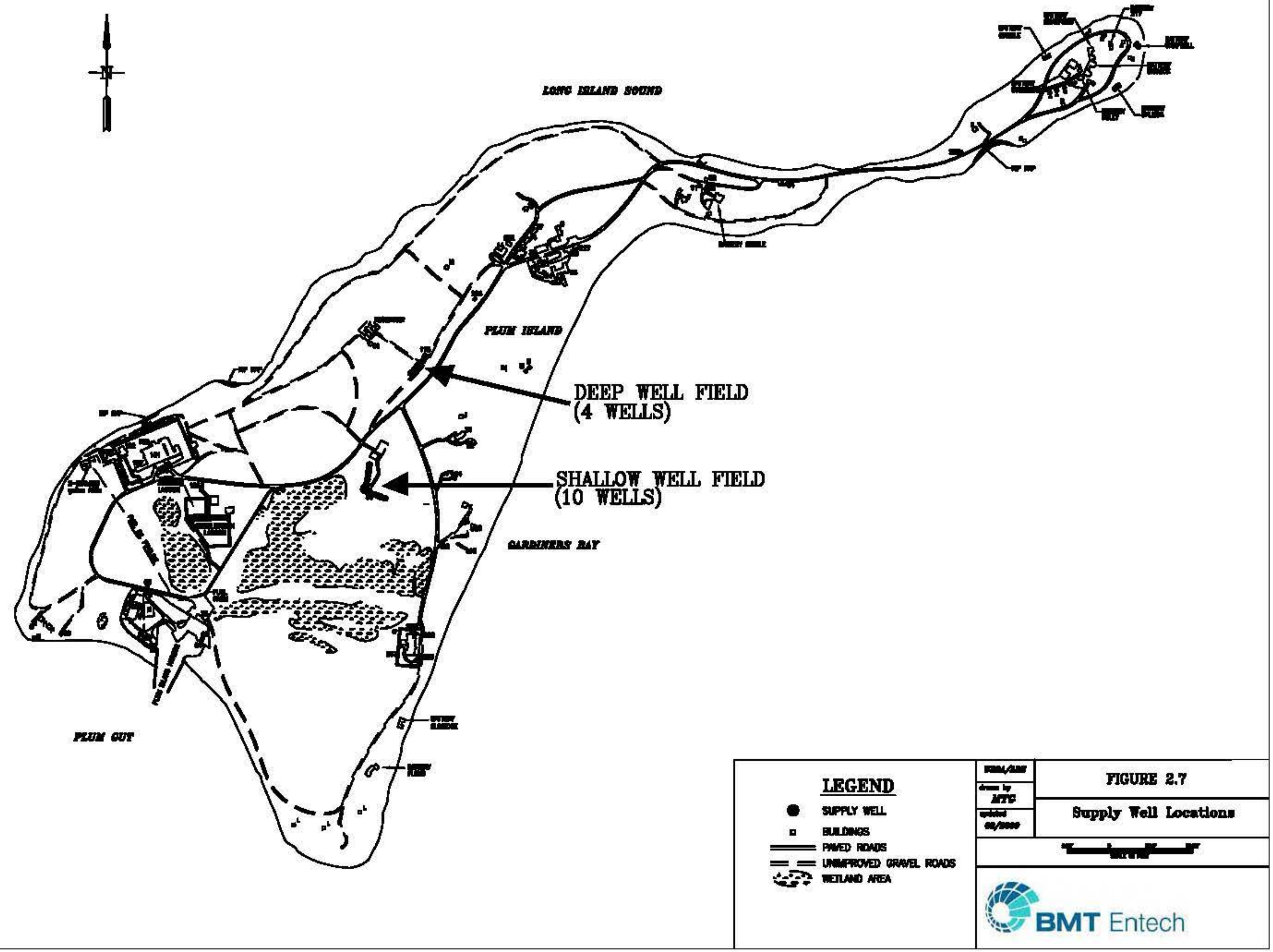


FIGURE 2.7

Supply Well Locations

3. WATER BUDGET ANALYSIS

Entech performed a water budget analysis based upon historical records and evaluation of current (1999) conditions. The purpose of the analysis was to predict the maximum amount of groundwater that may be sustainably withdrawn without adversely impacting water quality or availability. The water budget developed in this report builds upon work begun by Crandell (1962) and continued by ERM (1983).

A groundwater budget analysis involves determining typical values for aquifer recharge and for total groundwater losses. The resulting net recharge is used to augment a groundwater development program by estimating a safe yield. The safe yield is the maximum amount of groundwater that may be withdrawn in a given period without significantly impacting water quality or having some other undesirable effect. Undesirable effects may range from compaction of the aquifer and subsidence of the ground surface, to unacceptable drawdown in offsite wells, saltwater intrusion and draining of freshwater ponds and wetlands.

A water budget analysis never produces a single value for safe yield. Because of the numbers of variables involved, and the fact that impacts may be economics-related, wildlife-related or even political "captive", the resulting safe yield is best expressed as a range of values. In this Study, ranges were developed using two methods. These ranges were refined, based on professional judgement, to produce a single "target" value for safe yield. This target may be used for planning purposes, but it is important to remember that the actual safe yield might be found somewhere else in the calculated ranges.

3.1 Method 1

The first water budget calculation (Table 3.1) used data from the ERM (1983) report. These data were further qualified by applying typical error ranges taken from Fetter (1988). Measurements, such as rainfall, runoff, and evapotranspiration can be extremely inaccurate in the short-term. In the case of annual rainfall measurements, such as those used by ERM, accuracy improves greatly. Error ranges of 10% for runoff losses and 25% for evapotranspirative losses were applied to the ERM figures. No error ranges were applied to the annual rainfall values.

Annual net recharge ranges were developed based upon a typical rainfall year (45 inches) and a drought year (35 inches). Crandell (1962) recommends subtracting 50% from the net recharge to get the safe yield. This "buffer" is meant to minimize the chance of saltwater intrusion. The resulting safe annual yield for an average year is 39,000,000 gallons to 122,000,000 gallons. The safe annual yield based upon a drought year is 23,000,000 gallons to 94,000,000 gallons.

Table 3.1:
Annual Water Budget for Plum Island, New York
Calculation Method #1

	RUNOFF LOSSES(1)		Accuracy of Estimate(2)	EVAPOTRANSPIRATIVE LOSSES(1)		Accuracy of Estimate(2)	NET ANNUAL RECHARGE(3)				WEIGHTED VARIABILITY (+/-)				ADJUSTED RANGE OF ANNUAL RECHARGE(3)	SAFE ANNUAL YIELD
	Value	Units		Value	Units		Value	Units	Value	Units	Value	Units	Value	Units		(50% recharge)
AVERAGE YEAR 45 inches of rain	5.4	inches	+/- 10%	26	inches	+/- 25%	13.6	inches	161,000,000	gallons	7	inches	83,000,000	gallons	78,000,000 gallons - 244,000,000 gallons	**39,000,000 gallons - 122,000,000 gallons**
DROUGHT YEAR 35 inches of rain	4.2	inches	+/- 10%	21	inches	+/- 25%	9.8	inches	116,000,000	gallons	6	inches	71,000,000	gallons	45,000,000 gallons - 187,000,000 gallons	**23,000,000 gallons - 94,000,000 gallons**

Notes:

1) Losses estimated by ERM, 1983

2) Error estimates after Fetter, 1988

3) Calculations assume 0.68 square mile recharge area, after ERM, 1983

Example Calculation: Adjusted range of annual recharge for average year

STEP 1: 45 inches of rain - 5.4 inches of runoff - 26 inches of evapotrans. losses = 13.6 inches average net annual recharge

STEP 2: (5.4 inches of runoff X 0.1) + (26 inches of evapotrans. losses X 0.25) = 7.04 inches weighted variability

STEP 3: 13.6 inches average net annual recharge X 0.68 square miles of Plum Island X 4,014,489,600 square inches/square mile X 1 gallon/231 cubic inches = 160,718,613.9 gallons average net annual recharge

STEP 4: 7.04 inches weighted variability X 0.68 square miles of Plum Island X 4,014,489,600 square inches/square mile X 1 gallon/231 cubic inches = 83,195,517.81 gallons weighted variability

STEP 5: 161,000,000 gallons average net annual recharge (rounded) +/- 83,000,000 gallons weighted variability (rounded) = 78,000,000 gallons to 244,000,000 gallons adjusted range of annual recharge

3.2 Method 2

The second calculation method (Table 3.2) used typical recharge values, based on percentages of total rainfall, to determine safe yield values (Crandell, 1962). The resulting recharge values for average and drought years were, again, reduced by 50% to provide a “buffer” against saltwater intrusion. No error factors were applied to the final results. The calculated safe annual yield for an average year is 107,000,000 gallons. The calculated safe annual yield for a drought year is 52,000,000 gallons.

3.3 Water Budget Analysis Results

Crandell recommends a safe yield of 75,000,000 gallons per year (gpy), or an average of about 200,000 gallons per day (gpd). ERM, based in part on the results of a water supply study of Orient Point, recommends a safe yield range of 170,000 gpd to 200,000 gpd. Entech’s Study recommends a slightly more conservative figure of 150,000 gpd. The reasoning behind this more conservative target value follows.

The primary concern with regard to groundwater withdrawal at Plum Island is saltwater intrusion. Permanent damage to the sole source aquifer beneath Plum Island is unlikely to occur, since it is a water table aquifer, and comprised of coarse, relatively incompressible, material. Additionally, it is not possible that overpumping of PIADC wells could have any effect on groundwater withdrawals on Long Island, but potentially could affect freshwater wetlands on Plum Island. The results of the aquifer tests (described in Section 4) show that pumping at the Plum Island well fields affects a very small portion of the aquifer. Also, groundwater levels on Plum Island have changed very little since 1964. The average depth to water in the Deep Well Field during the 1964 well acceptance tests was 35 feet. The average 1999 depth to water in the observation wells, installed in the same well field for the aquifer tests, was 36 feet. As the records are unclear with regard to measuring points for the 1964 water levels, it is possible that those levels are off by as much as one foot, and the 1964 and 1999 levels are essentially equal. Whatever the case, no dramatic decrease in water levels have occurred. On the other hand, increases in chloride levels during pumping are well documented on Plum Island.

No temporal data exists on the depth of the saltwater-fresh water interface below the island. According to the Ghyben-Herzberg Principle, the interface should be approximately 100 feet below sea level at the center of the island. Based upon the relatively unchanged height of the water table above sea level, the depth to the interface has probably changed very little over time. However, it might be prudent to install several sentry wells to monitor the depth of the interface. The results of chloride sampling from these wells could be used to fine tune pumping rates, and to develop a more accurate safe yield. In fact, sentry wells should probably be installed prior to the finalization of any major PIADC development plans.

Table 3.2:
Annual Water Budget for Plum Island, New York
Calculation Method #2

	TYPICAL RECHARGE VALUE(1)	NET ANNUAL RECHARGE(2)				SAFE ANNUAL YIELD
	(percentage of rainfall)	Value	Units	Value	Units	(50% recharge)
AVERAGE YEAR 45 inches of rain	40%	18	inches	213,000,000	gallons	**107,000,000 gallons**
DROUGHT YEAR 35 inches of rain	25%	8.75	inches	103,000,000	gallons	**52,000,000 gallons**

Notes:
1) Recharge percentages after Crandell, 1962
2) Calculations assume 0.68 square mile recharge area, after ERM, 1983

Example Calculation: Net annual recharge for average year

STEP 1: 45 inches of rain X 0.4 (typical recharge as percentage of rainfall) = 18 inches net annual recharge

STEP 2: 18 inches net annual recharge X 0.68 square miles of Plum Island X 4,014,489,600 square inches/square mile

X 1 gallon/231 cubic inches = 213,000,000 gallons net annual recharge (rounded)

A safe yield target value of 150,000 gpd, or 55,000,000 gpy, is proposed for planning purposes. The safe annual yield range for drought conditions, calculated by Method 1, is a conservative and reasonable range. The midpoint of this range is 160,000 gpd. This value is also in the lower 25% of the average (non-drought) year safe yield range, reinforcing the assumption that it is a conservative value. Rounding this figure to 150,000 gpd, or about 55,000,000 gpy, leads to the final recommended target value.

Between 1973 and 1999, groundwater withdrawals at Plum Island averaged about 32,000,000 gpy, or about 90,000 gpd (Table 3.3). The year with the highest recorded withdrawals was 1982, when 40,275,600 gallons, or an average of about 110,000 gpd, were withdrawn. As Figure 3.1 indicates, the late 1970s to early 1980s was the period of highest water use. In recent years, water use has diminished significantly. Groundwater withdrawals now average about 25,000,000 gpy or 70,000 gpd. This is only about 50% of the target safe yield of 150,000 gpd or 55,000,000 gpy.

3.4 Recommendations

Safe Yield. The target safe yield of 55,000,000 gpy should not be exceeded. If sentry wells are installed, this figure may be adjusted based on the monitoring of salinity levels at depth. The adjusted safe yield should be taken as the actual safe yield, and should not be exceeded.

Sentry Wells. Three sentry wells should be installed to monitor the saltwater-fresh water interface below the island (Figure 3.2). One well should be placed adjacent to, and just seaward of, each of the two well fields. These wells (S-1 and S-2) would provide data on salinity changes in the immediate vicinity of the production wells. The third well (S-3), located on the north end of the island, would provide background salinity fluctuation data unrelated to pumping.

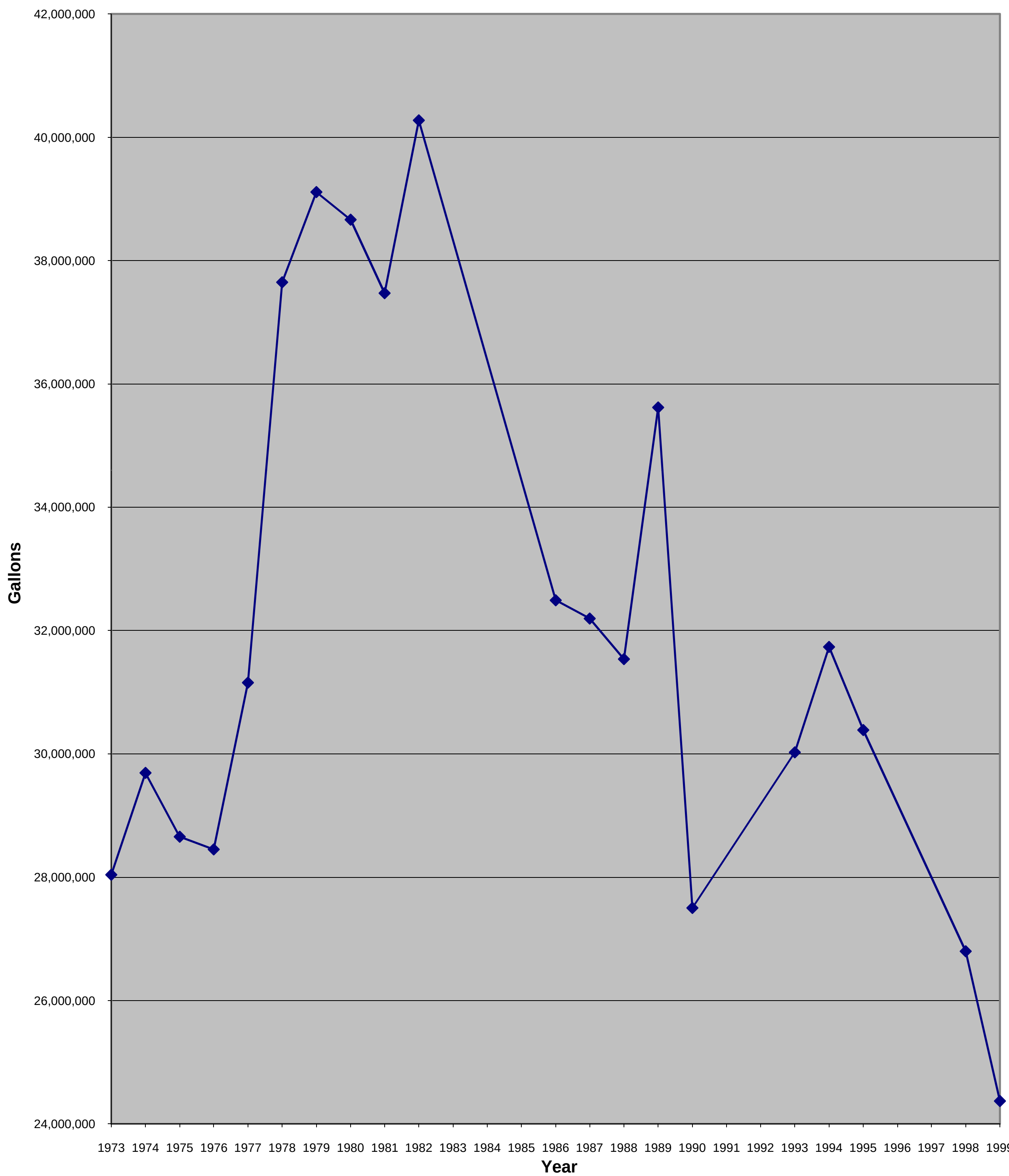
The sentry wells should be deep enough to detect saltwater encroachment at an early stage. However, screening the wells at or very close to the interface might result in highly fluctuating and difficult to interpret salinity levels. Screening the wells 10 to 15 feet above the interface should provide early warning of encroachment without producing data that are difficult to comprehend (ERM, 1983). Approximate depths to the interface at each of the proposed sentry well locations are: S-1, 90 feet; S-2, 100 feet; S-3, 75 feet.

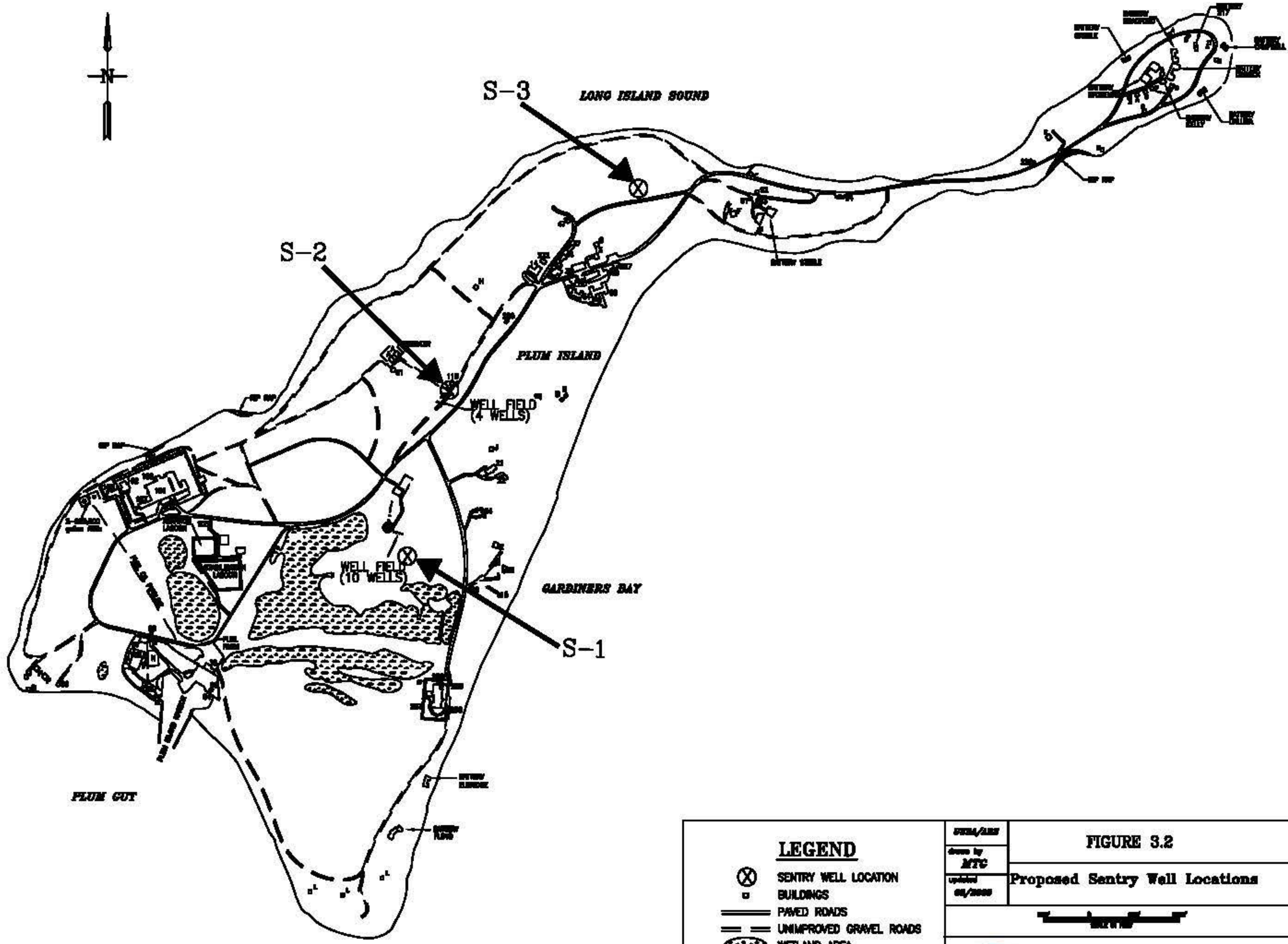
Sentry well drilling should be accomplished using a water-rotary drill rig. Each boring should be advanced to a depth slightly below the expected interface depth at that location. The drill rate should be closely monitored, with any significant changes being accounted for with split-spoon sampling. All lithologic changes should be noted. Once drilled, each boring should be geophysically logged using a 64-inch normal resistivity tool. Once the geophysical data have been corrected for lithologic changes, the resulting resistivity is directly related to the ionic concentration of the formation water. The well screen should be

Table 3.3
Groundwater Withdrawls at Plum Island
1973 - 1999

Month	Year	Gallons Pumped	Gallons per Day	Notes
Total	**1973**	**28,039,200**	**77,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1974**	**29,691,600**	**81,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1975**	**28,654,800**	**79,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1976**	**28,450,800**	**78,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1977**	**31,156,800**	**85,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1978**	**37,646,400**	**103,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1979**	**39,111,600**	**107,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1980**	**38,662,800**	**106,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1981**	**37,470,000**	**103,000**	**Estimated from incomplete data in ERM, 1983**
Total	**1982**	**40,275,600**	**110,000**	**Estimated from incomplete data in ERM, 1983**
May	1985	3,024,150		Estimated 97,500 gpd for 5/1 - 5/5
December	1985	2,742,600		
Total	**1985**	**insufficient data**		**No data for 1/11/85 - 5/5/85**
January	1986	3,574,400		
July	1986	2,637,500		No data for 7/1
Total	**1986**	**32,492,100**	**89,000**	
January	1987	2,639,000		
July	1987	2,923,700		No data for 7/1, 7/2
Total	**1987**	**32,192,700**	**88,000**	
January	1988	2,695,300		
July	1988	2,776,000		
Total	**1988**	**31,536,600**	**86,000**	
January	1989	2,514,100		
July	1989	3,387,300		
Total	**1989**	**35,619,000**	**98,000**	
January	1990	2,782,500		
July	1990	2,352,800		
Total	**1990**	**27,500,000**	**75,000**	**No data for 11/20 - 12/31. Estimated ~3,000,000 gal for this period**
				No data for 11/20/90 - 9/17//92
January	1993	2,293,000		
July	1993	2,214,100		
Total	**1993**	**30,023,000**	**82,000**	
January	1994	2,521,700		
July	1994	3,254,000		
Total	**1994**	**31,733,600**	**87,000**	
January	1995	2,301,600		
July	1995	2,607,500		
Total	**1995**	**30,385,800**	**83,000**	
				No monthly totals for 1996, 1997 (psi only)
February	1998	2,190,000		
July	1998	3,330,000		
Total	**1998**	**26,800,000**	**73,000**	**Estimated ~2,200,000 gallons for January**
January	1999	1,680,000		
July	1999	2,600,000		
Total	**1999**	**24,370,000**	**67,000**	
	AVG	**32,090,620**	**88,000**	
	MAX	**40,275,600**	**110,000**	

Figure 3.1:
PIADC Groundwater Withdrawals
1973 - 1999





LEGEND

- ⊗ SENTRY WELL LOCATION
- ▫ BUILDINGS
- PAVED ROADS
- UNIMPROVED GRAVEL ROADS
- WETLAND AREA

drawn by MTC

FIGURE 3.2

Proposed Sentry Well Locations

BMT Entech

set just above the point where resistivity begins to decrease significantly. The screen should be no more than 10 feet in length. The long-term monitoring of a discrete short depth interval rather than a longer one will allow for more accurate tracking of any movement in the interface.

The total cost of installing the sentry wells (1999 dollars) would be approximately $13,000 (Appendix C, Table C.1).

Chloride and/or total dissolved solids (TDS) levels should be monitored at the bottom of the sentry wells. This can be accomplished in several ways. A submersible pump can be lowered to the desired depth, and the sample pumped to the surface to be analyzed using a portable instrument that measures salinity or conductivity. Alternatively, a dedicated submersible water quality logger can be installed in each well. Such a unit would monitor salinity continuously and store data onboard. The data would be retrieved through a connection to a computer. Finally, a portable water quality meter equipped with a sensor that can be lowered to depth could be used.

Salinity/TDS monitoring should be conducted on a regular schedule. Initially, quarterly sampling would be desirable. This would allow for the identification of any seasonal fluctuations and might identify, in the course of a year, any considerable trend. If levels do not vary greatly, sampling frequency might be reduced. However, the low cost and simplicity of salinity/TDS monitoring, along with its importance at Plum Island, suggest it should be an integral part of quarterly water quality monitoring.

Maintenance of “Green” Recharge Areas. Construction of impermeable surface barriers, such as parking lots, should be avoided in the areas upgradient from the well fields. Such development inhibits the infiltration of meteoric water, and reduces recharge to the aquifer. The areas that should remain relatively undeveloped are the high portions of the Wellhead Protection Area (Figure 8.1) that will be discussed in Section 8.

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4. AQUIFER TESTING

In order to update PIADC's prior (1983) understanding of the physical condition and quality of its potable water resources, Entech conducted 24-hour aquifer pumping tests at each of the two PIADC well fields. The purpose of these tests was to characterize the hydraulic properties of the sole source upper glacial aquifer beneath Plum Island, assess radii of pumping influence, and determine whether either of the two well fields might potentially be affected by groundwater contamination originating from nearby Waste Management Areas (WMAs) or Areas of Potential Concern (AOPCs). WMAs and AOPCs are sites within the confines of the 840-acre island where waste disposal operations occurred during USDA-ARS's control of Plum Island.

4.1 Summary of Pumping Test Results

The tests were conducted in November of 1999. Pumping test results (Table 4.1) are indicative of a highly transmissive aquifer (88,000 to 122,000 gallons per day per foot [gpd/ft]). Average hydraulic conductivities (1,100 to 1,530 gpd/ft^2) are as would be expected in a coarse sandy aquifer (Heath, 1983). Average storativity values (4×10^{-3} to 1×10^{-2}) are somewhat lower than expected. This may be due to the presence of fine sand in the pumping zones.

Distance-drawdown analyses, estimating the radius of the cone of depression after 24 hours of pumping, were performed for each of the well fields. The radius at the Deep Well Field is estimated to be 170 feet at a pumping rate of 83 gpm. At the Shallow Well Field, where smaller (40 gpm) pumps were actively used in 1999, the pumping radius is estimated at 70 feet.

Groundwater seepage velocities and travel times along three flow paths were estimated based upon the pumping test results. The flow paths, established by ERM (1983), all begin at the island's groundwater divide, and extend to the shoreline (Figure 4.1). Velocity and travel time estimates are presented in Table 4.2.

The travel time calculations suggest that the fresh water lens beneath Plum Island flushes completely within approximately 20 years.

4.2 Pumping Test Design and Implementation

The pumping tests were conducted in accordance with the Pumping Test Specification contained in Entech's Final CERCLA Sampling and Analysis Plan, dated October 1999 (Appendix D to this report). A summary description of pumping test procedures and a more detailed discussion of results follows.

Table 4.1:
Aquifer Pumping Test Results

	Hydraulic Conductivity		Transmissivity		Storativity		Radius of Cone of Depression
	Average	**Range**	**Average**	**Range**	**Average**	**Range**	
TEST 1 (Deep Well Field: Wells 11-14) **Pumping Well #14** **Pumping Rate 83 gpm**	1,500 gpd/ft^2 7.10×10^{-2} cm/s	1,470-1,530 6.95×10^{-2}-7.24×10^{-2}	119,000 gpd/ft	117,000-122,000	1×10^{-2}	9.56×10^{-3}-$1.27\text{-}10^{-2}$	~170 ft
TEST 2 (Shallow Well Field: Wells 1-10) **Pumping Well #9** **Pumping Rate 40 gpm**	1,200 gpd/ft^2 5.68×10^{-2} cm/s	1,100-1,260 5.20×10^{-2}-5.96×10^{-2}	95,000 gpd/ft	88,000-100,500	4×10^{-3}	3.30×10^{-3}-4.29×10^{-3}	~70 ft

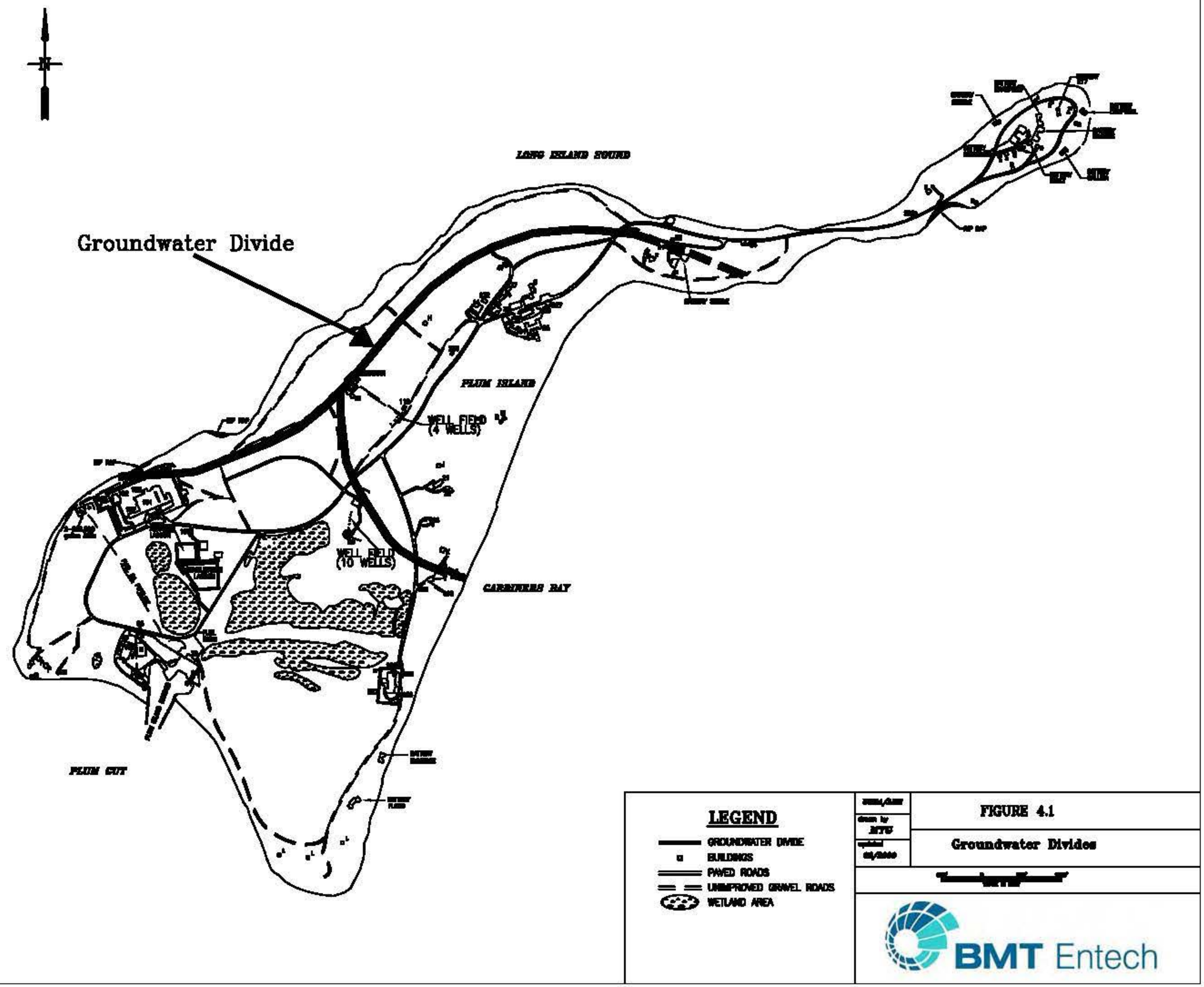


FIGURE 4.1

Groundwater Divides

Table 4.2:
Groundwater Velocities and Travel Times

	Average Lateral Velocity (ft./day)	Travel Time
Flow Path A **Divide to North Shore**	3	225 days 0.62 years
Flow Path B **Divide to Southeast Shore**	1.3	1,200 days 3.3 years
Flow Path C **Southern Divide Extension to Southwest Shore**	0.56	6,604 days 18.1 years

Example Calculation: Travel time, in days, along Flow Path A

STEP 1: 1,500 gpd/square foot [hydraulic conductivity] X 0.134 [conversion factor] =
201 ft./day hydraulic conductivity

STEP 2: 201 ft./day [hydraulic conductivity] X 0.0037 [gradient]/0.25 [porosity] =
3 ft./day (rounded) average lateral velocity

STEP 3: 675 ft. [Flow Path A] / 3 ft./day [average lateral velocity] = 225 days

4.2.1 Well Field Descriptions

The aquifer tests were conducted at PIADC's two well fields which provide all drinking water and process water (e.g., cooling, heating, heat-treated decontamination) for Plum Island. The "Shallow Well Field", adjacent to Building 59, consists of ten wells, numbered 1 through 10. These wells are all approximately 30 feet deep, and, in 1999, contained pumps rated at 25-40 gallons per minute (gpm). The "Deep Well Field", adjacent to Building 115, consists of four wells, numbered 11 through 14. These wells are all approximately 60 feet deep. Wells 13 and 14 contained, at the date of this investigation, pumps rated at 80-100 gpm. Wells 11 and 12 did not have functioning pumps at the time of this Study.

4.2.2 Previous Aquifer Tests at Plum Island and Vicinity

The only aquifer tests known to have been performed on Plum Island were the 1964 well acceptance tests of Wells 11-14. These were single-well specific capacity tests performed by the well drillers immediately after installation of the wells. Many tests have been performed on the upper glacial aquifer of Long Island, which is the same geologic unit found beneath Plum Island (McClymonds, 1972). Hydraulic conductivities tend to be high in this unit, with an average of 1,700 gpd/ft^2 in the McClymonds study.

4.2.3 Aquifer Test Hypotheses

A multiple-well aquifer pumping test provides data on the following aquifer characteristics: hydraulic conductivity, transmissivity, storativity and radius of the pumping cone of depression. Existing literature and the data generated during the 1964 well acceptance tests were consulted to develop expected ranges for these values.

In reviewing the results of a number of aquifer tests on Long Island, McClymonds et. al. (1972) estimated the average hydraulic conductivity in the upper glacial aquifer at 1,700 gpd/ft^2. The average for north central Suffolk County, near Plum Island, was 1,500 gpd/ft^2.

The average transmissivity of the upper glacial aquifer was 200,000 gpd/ft in the McClymonds study. As part of the current investigation, transmissivity at Plum Island was estimated using data from the 1964 Well #14 acceptance test. Depending on input parameters, the transmissivity estimate was between 35,000 and 40,000 gpd/ft. This single well method of determining transmissivity is considered much less reliable than an actual multiple well test. In fact, McClymonds found that well acceptance tests on Long Island consistently gave significantly lower transmissivities than those obtained from traditional multiple well tests.

Storativity data were not reported by McClymonds. In general, the storativity of an unconfined aquifer is equal to its specific yield, and ranges between 1×10^{-2} and 3×10^{-1} (Driscoll, 1986).

The well acceptance test at Well #14 made use of some ill-defined observation wells. For this reason, it is only possible to estimate a radius for the pumping cone of depression during the acceptance test at between 10 and 20 feet, at a withdrawal rate of 61 gpm.

Predicted Results

The McClymonds hydraulic conductivity average of 1,500 gpd/ft^2 for north central Suffolk County was chosen as a reasonable estimate based upon the proximity of the data points to Plum Island.

Transmissivity is equal to hydraulic conductivity multiplied by aquifer thickness. The aquifer thickness was estimated at 80 feet at each of the PIADC well fields, based upon Crandell (1962). This thickness multiplied by the predicted hydraulic conductivity of 1,500 gpd/ft^2 gives a transmissivity of 120,000 gpd/ft. While this is lower than the average McClymonds calculated for the upper glacial aquifer, the average aquifer thickness in the McClymonds study was 140 feet. An expected transmissivity of approximately 120,000 gpd/ft was deemed reasonable for this Study.

The generally accepted range of storativity values for unconfined aquifers, 1×10^{-2} to 3×10^{-1}, was the expected range for this Study.

The pumping radius for the Deep Well Field Well #14 acceptance test was estimated at approximately 20 feet at 61 gpm. The pump that is currently (1999) installed in Well #14 was known to be pumping at a rate of 83 gpm before Entech began the aquifer tests at Plum Island. Because a gauge at the Building 59 Pumphouse was not working prior to the tests, the pumping rate at Shallow Well Field Well #9 could not be determined with precision before the test. It was thought to be operating at 25-30 gpm. Based on these figures, general ranges were predicted for the pumping radii during the 1999 tests. The radius at the Deep Well Field (#14) was predicted to be between approximately 25 and 35 feet. The radius at the Shallow Well Field (#9) was predicted to be between 8 and 10 feet.

Conductivity at the Deep Well Field

Pumping the Deep Well Field wells at the rate of 80-90 gpm produced water of higher salinity than that pumped from the Shallow Well Field. The implication is that a saltwater intrusion cone rises below the pumping well, increasing the salt content of the pumped water. For this reason, conductivity levels in Observation Well B-6, 8 feet from the pumping Well #14, were expected to rise during Test 1.

Boundary Conditions

The lateral extent of any particular glacial outwash lens is often quite limited in comparison to the size of the entire deposit of outwash. Zones of coarse, highly conductive material are usually surrounded by less conductive areas. For this reason, low-flow boundaries are commonly encountered at some point during a pumping test in glacial outwash (Driscoll, 1986). The result is an essentially instantaneous decrease in the slope of a time-drawdown plot of the test data.

As McClymonds does not report any instances of low-flow boundaries being encountered, no such conditions were expected in this Study.

4.2.4 Pumping Test Field Procedures

In September and October of 1999, eleven observation wells were installed at the production well fields. Their distances from the pumping wells were based upon the predicted drawdowns at each field. The Pumping Test Specification is presented in Appendix D.

Observation Well Installation at the Shallow Well Field

Five observation wells (Wells A-1 through A5) were installed at the Shallow Well Field (Table 4.3). Boreholes were advanced using a truck-mounted Geoprobe unit. The wells were constructed of 1" diameter PVC and were built inside 2 1/8" Geoprobe^{tm} rods. Screened intervals were approximately 15-25 feet bgs. This is the same interval screened in pumping Well #9. The screen slot sizes are 0.010". Observation well construction diagrams and boring logs are presented in Appendix E.

Figure 4.2: Well #9 (manhole) and array of observation wells.

Observation Well Installation at the Deep Well Field

Six observation wells (Wells B-1 through B-6) were installed at the Deep Well Field (Table 4.3). Boreholes were advanced using a truck-mounted Simco 2800 drill rig equipped with 4 1/4" hollow-stem-augers. The wells were built inside the augers. Observation Wells B-1 through B-5 were constructed of 1" PVC, while Well B-6 was built using 3" PVC. Well B-6 was designed to accommodate a Troll 8000^{tm}

Table 4.3:
Observation Well Arrangements

Observation Well	**Distance From Pumping Well #9 (ft.) Shallow Well Field**
A-1	3.5
A-2	6.8
A-3	10.3
A-4	16.8
A-5	30.8
Observation Well	**Distance From Pumping Well #14 (ft.) Deep Well Field**
B-1	4.8
B-2	10.7
B-3	18.1
B-4	32.6
B-5	62.7
B-6	8

data logger with a conductivity probe. All of the wells were screened at 45-55 feet bgs. This is approximately the same interval at which the pumping Well #14, is screened. All screen slot sizes are 0.010".

Pressure Transducer Placement

Original work plans called for the use of six pressure transducers at each well field. Due to equipment failures, only four transducers were available for use at the Deep Well Field. By the time testing at the Shallow Well Field was initiated, five working transducers were available.

Transducer Placement at the Deep Well Field

Transducers were set in Observation Wells B-1, B-2, B-3 and B-4. They were lowered to the bottom of each well, and then pulled up approximately one foot. It was not possible to place a transducer in Pumping Well #14 due to the design of its discharge assembly. A Troll 8000 data logger was placed in Well B-6 (a three-inch well). Its purpose was to monitor any changes in groundwater conductivity (i.e., saltwater intrusion) during the pumping test. The conductivity probe was set at approximately 52 feet below ground surface.

Figure 4.3: Hermit datalogger setup at Well #14. Pipe on far right is Observation Well B-6.

Transducer Placement at the Shallow Well Field

Transducers were set in Pumping Well #9 and Observation Wells A-1, A-2, A-4 and A-5. They were lowered to the bottom of each well, and then pulled up approximately one foot.

Pumping Test 1 Procedure

The test at the Deep Well Field was designated Test 1. The transducers and Troll 8000 data logger were set in the wells on November 1, 1999 and allowed to equilibrate for approximately 24 hours. Water and conductivity levels during this pre-test were recorded in order to establish baseline conditions. These pre-test water levels were compared with local tidal data to determine the extent to which the tides affect water levels in the well field. No effect was seen (Appendix F).

Pumping Test 1 began on November 2, 1999. Well #14 was turned on at 0910, and pumped continuously at 83 gpm until 0935 on November 3, 1999. Water level data were recorded until 1245 on November 3, 1999.

Water levels recovered to near static levels within approximately three hours. All water and conductivity level data were downloaded to a personal computer on the afternoon of November 3, 1999.

Pumping Test 2 Procedure

The test at the Shallow Well Field was designated Test 2. The transducers were set in the wells on November 3, 1999, and allowed to equilibrate for approximately 18 hours. Water levels during this pre-test were recorded in order to establish baseline conditions. No tidal effects were observed (Appendix F).

Pumping Test 2 began on November 4, 1999. Well #9 was turned on at 0732, and pumped continuously at 40 gpm until 0620 on November 5, 1999. Water level data were recorded until 0900 on November 5, 1999. The pump was turned off about one hour early because the water storage tower was overflowing. Water levels recovered to near static levels within approximately three hours. All water level data were downloaded to a personal computer on the morning of November 5, 1999.

4.2.5 Analysis of Test Data

All pumping test data were analyzed using AquiferTest for Windows^{tm} software, version 2.55. Raw data were converted into Excel files, and then imported into AquiferTest. Each test was analyzed using three different methods: the standard Theis method (corrected for unconfined conditions), the Cooper and Jacob straight line method (corrected for unconfined conditions), and the Neuman method for unconfined aquifers. Each of these methods is a graphical approach that uses time-drawdown data at different distances from a pumping well to derive aquifer characteristics such as, hydraulic conductivity, transmissivity and storativity. Data gathered from an aquifer test are plotted and compared (manually or electronically) with standard type curves (Appendix B). Once a best fit has been found, aquifer characteristics may be calculated directly from the graph.

The Theis Method uses the Theis curve, also known as the reverse type curve, which is shaped like the cone of depression near the pumping well (Fetter, 1988). This method was developed for the analysis of conditions in confined aquifers. Since the aquifer tested in this study is unconfined, the Jacob correction for unconfined conditions was applied to all drawdown data before applying the Theis Method. The equation for the correction is:

$$s_{cor} = s - (s^2/2D)$$

where,

s_{cor} = the corrected drawdown,

s = the measured drawdown, and

D = the original saturated aquifer thickness (Waterloo, 1995).

The Jacob correction allows an aquifer test analytical method to better simulate conditions in a water table aquifer.

The Cooper and Jacob Straight Line Method is a simplification of the Theis Method. It ignores some early time data in order to plot results on a straight line (Waterloo, 1995). The Jacob correction was applied to data before use of the Cooper and Jacob Method.

The Neumann Method is designed specifically for unconfined conditions. It uses two sets of type curves. One set represents data from early in a pumping test, while the second set approximates later conditions when gravity drainage becomes more significant (Waterloo, 1995). Because the early and late type curves have different shapes, it is not necessary to apply the Jacob correction to drawdown data before using the Neumann Method.

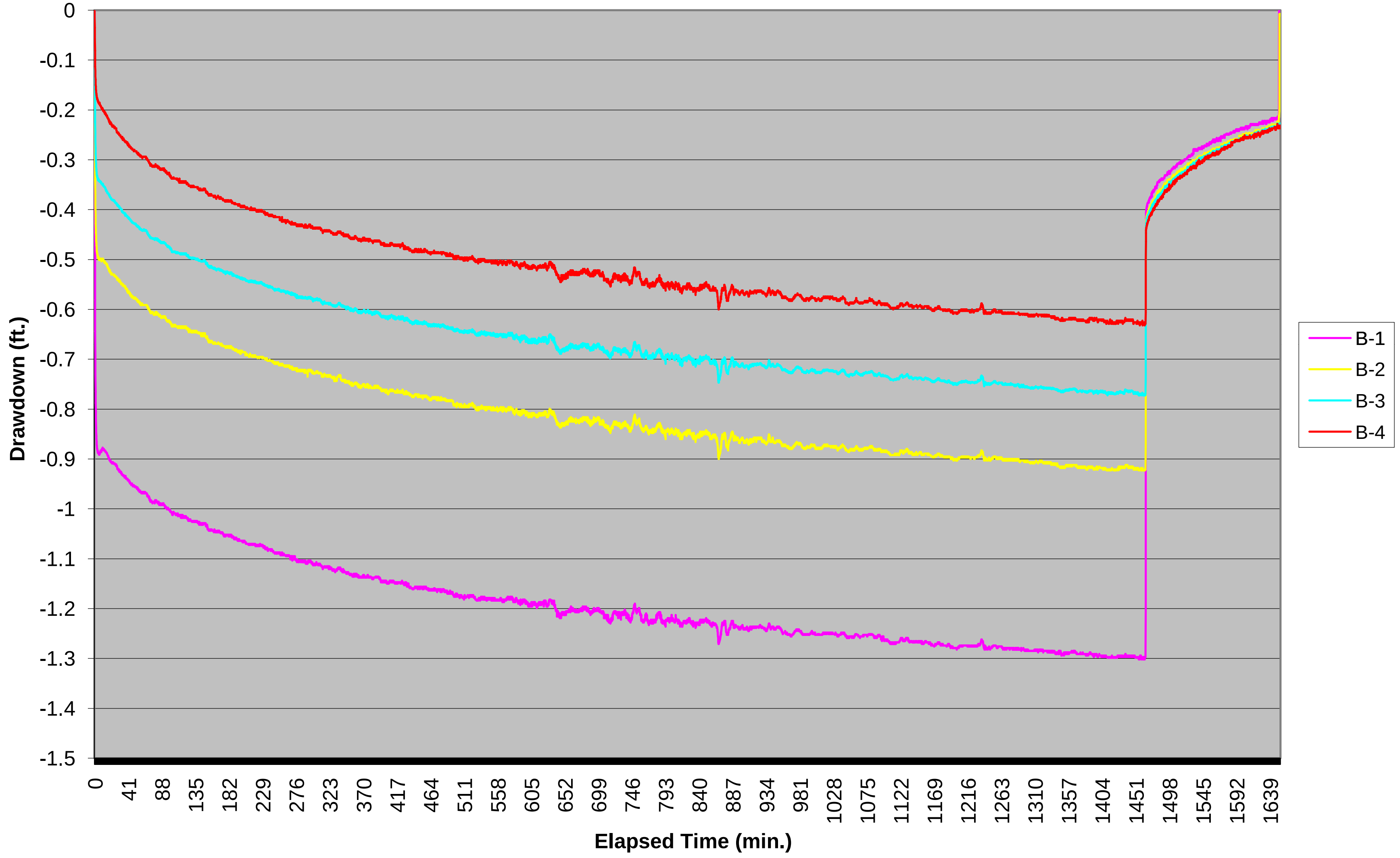
Pre-Test Water Levels

Water levels collected during the equilibration periods before each test were graphed, and compared with tide data collected during the same periods at Montauk Point, Long Island, and New London, Connecticut (Appendix F). These comparisons showed no tidal influence on water levels at either of the PIADC well fields.

Test 1 Analysis

The Test 1 data (Deep Well Field) were analyzed using two different sets of initial conditions. The first set of analyses excluded water level data collected from Observation Well B-1. This was done to exclude any vertical flow components of the well discharge from the data analysis. Such vertical flow in the vicinity of a pumping well often makes up a significant portion of discharge in Long Island's upper glacial aquifer (McClymond's, 1972). The second set of analyses used water level data from all observation wells. Water level drawdown versus time during the test is plotted in Figure 4.4.

Fig. 4.4: Test 1 (Deep Wells) Drawdown Data



Test 2 Analysis

The Test 2 data (Shallow Well Field) were also analyzed using two different sets of initial conditions. The first set of analyses used data from all observation wells. The second excluded data from Observation Well A-1. Water level drawdown versus time during the test is plotted in Figure 4.5.

Determination of Groundwater Velocities and Travel Times

Groundwater seepage velocities were determined using the following relationship:

$$U=Ki/n,$$

where U = average groundwater velocity (ft/day)

K = hydraulic conductivity (gpd/ft^2)

i = hydraulic gradient (dimensionless)

n = effective porosity (dimensionless).

Velocities were calculated using the average hydraulic conductivity for Test 1, of 1,500 gpd/ft^2. An effective porosity of 0.25 was estimated based upon observations of drill cuttings during well installation. The island has one major and one minor groundwater divide which apportion flow into three regions (Figure 4.1). The same hydraulic gradients estimated along flow paths in each region in the ERM report (1983) were used in this study. Lateral velocities varied by region (Table 4.2). The highest velocity (33 ft./day) was calculated for the steep flow path from the central divide to the north shore. The lowest velocity (0.56 ft./day) was calculated for the relatively level path from the southern divide extension to the southwest shore.

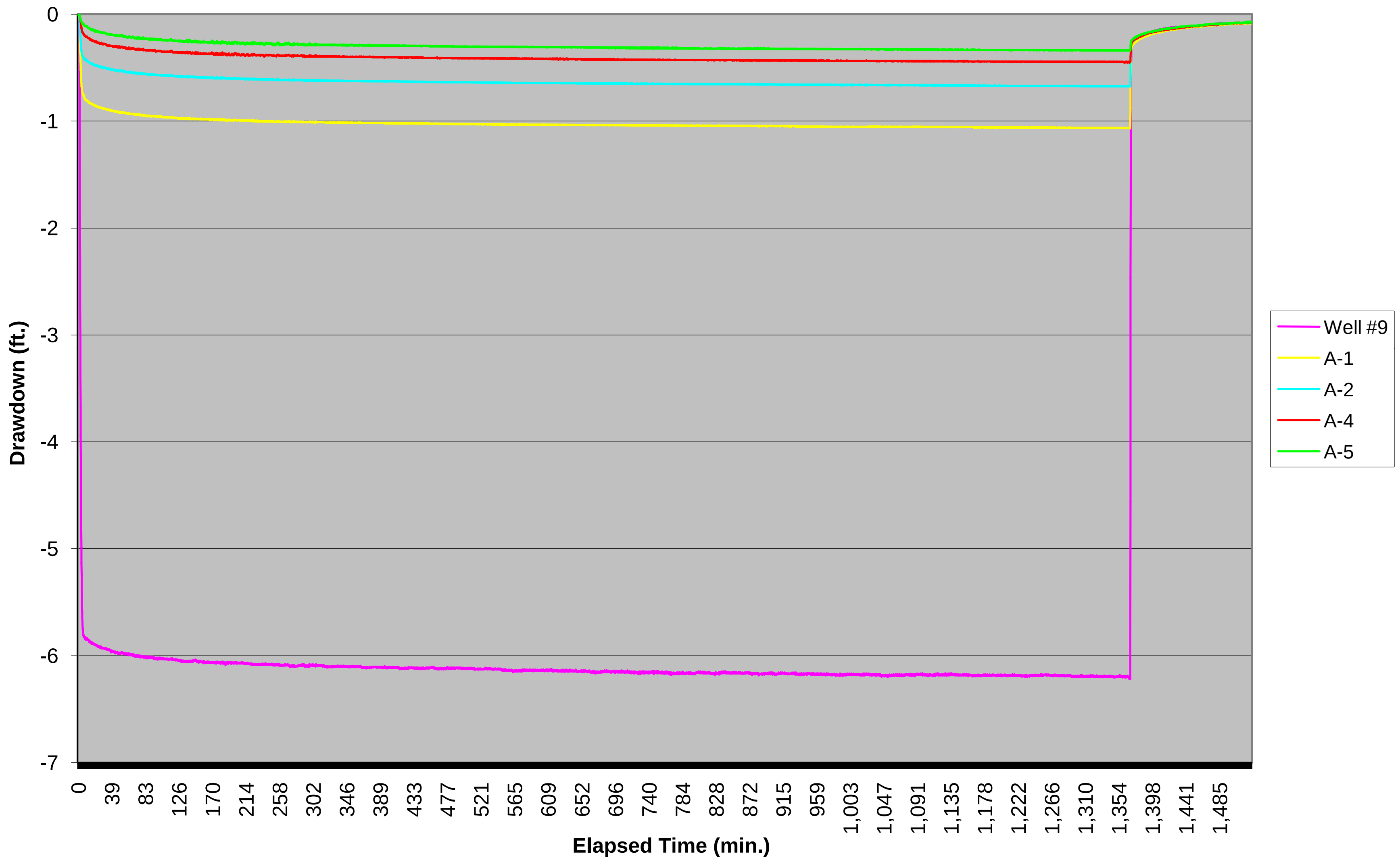
4.2.6 Discussion of Pumping Test Results

For each test, transmissivity and hydraulic conductivity values were determined by averaging the results of six analyses. The Theis, Cooper-Jacob, and Neuman solutions were calculated for each of two sets of initial conditions. Storativity values were determined by averaging the results of two analyses. As only the Neuman analysis provides a storativity solution, it was the Neuman results, calculated for each of the two sets of initial conditions, that were averaged to determine storativity.

Test 1 Results

The two different models for Test 1 (with and without Observation Well B-1 data) produced nearly identical results for hydraulic conductivity and transmissivity (Table 4.1). The hydraulic conductivity average of

Fig. 4.5: Test 2 (Shallow Wells) Drawdown Data



1,500 gpd/ft^2 is equal to the predicted value. The transmissivity average of 119,000 gpd/ft is essentially equal to the predicted value of 120,000 gpd/ft.

The storativity average of $1x10^{-2}$ is equal to the low end of the range for a typical unconfined aquifer. This low value may be due to much of the aquifer above the screened interval being composed of very fine sand.

The radius of the cone of depression after 24 hours of pumping was approximately 170 feet. This is significantly greater than the predicted radius of 25-35 feet. Two reasons for this discrepancy are readily apparent. The first is the fact that the shallow portion of the aquifer consists of finer material than was initially anticipated. The second reason stems from the unreliable nature of well acceptance test data, particularly in the upper glacial aquifer of Long Island. It was well acceptance test data that provided the basis for the pre-test pumping radius estimate.

Analysis of time-drawdown data indicates no low-flow boundaries were encountered during pumping, as predicted.

Conductivity Probe Results

Conductivity of the water in Observation Well B-6 was expected to increase as a result of pumping and upconing of saltwater. In fact, levels showed a slight decrease (~9%) during Test 1. The decrease may be a result of the well essentially being developed (i.e., suspended solids being removed) during the pumping test. It may also be that pumping water across the conductivity probe actually causes a very slight change in the probe’s ability to measure properly. This second scenario seems logical considering the fact that conductivity returned to pre-test levels immediately upon the cessation of pumping.

Two possible reasons are suggested for conductivity not *increasing* during the pumping test. The first is that the test may not have lasted long enough for salt water intrusion to occur. This seems unlikely, since the production wells are rarely pumped for more than 24 hours, yet salinity has been known to increase. The second possibility is that the salt water intrusion cone rose up to the pump in Well #14, but did not extend laterally to the portion of Observation Well B-6 that contained the conductivity probe. This seems likely, since the conductivity probe was at a depth equal to, or slightly shallower, than the intake of the pump in Well #14. It is also likely that such an intrusion cone would be very steep and narrow in the coarse material that underlies the well field. Conductivity, drawdown and temperature data collected by the Troll 8000 data logger in Observation Well B-6 are presented in Appendix G.

Test 2 Results

The hydraulic conductivity average of 1,200 gpd/ft^2 is slightly lower than the predicted value of 1,500 gpd/ft^2 (Table 4.1). The transmissivity average of 95,000 gpd/ft is slightly lower than the predicted value of 120,000 gpd/ft. These results are likely due to the fact that wells in the Shallow Well Field are screened above known gravel zones. As a result, all of the water pumped from this field is drawn through fine sand, rather than the sand and gravel typical of screened intervals in the upper glacial aquifer, including the Deep Well Field.

The storativity average of 4×10^{-3} is low for an unconfined aquifer. This may be due to the fine nature of the material in the pumping zone and/or it may be a result of only having two data points to average.

The radius of the cone of depression after 24 hours of pumping was approximately 70 feet. This is significantly greater than the predicted radius of 8-10 feet. Three reasons for this discrepancy are readily apparent. The first is the fact that the actual pumping rate during the test was 40 gpm, not the 25-30 gpm that had been expected. Second, the wells at the Shallow Well Field are entirely screened in fine sand. Prior to well installation, these wells were thought to be set in gravel. A fine sand would be expected to produce a larger cone of depression because of its lower hydraulic conductivity. Finally, well acceptance test data are known to be unreliable indicators of hydraulic properties, particularly in the upper glacial aquifer of Long Island.

Analysis of time-drawdown data indicates no low-flow boundaries were encountered during pumping, as predicted.

4.2.7 Validity of Test Results

Numerical models of natural systems, rather than being a collection of facts, are really a form of complex scientific hypothesis. They can never be verified (Oreskes, 1994). In particular, a pumping test represents a complex system where input parameters can never be known completely and the operational processes, themselves, are not entirely understood. Pumping test results are non-unique; that is, they can be produced by different sets of inputs. Additionally, they may not be accurate in predicting future results.

However, pumping tests can be used to support the probability that a set of hypotheses is representative of reality. To do this, more than one model should be created using different initial conditions (Wuolo, 1993). The results can then be compared with original hypotheses.

In this Study, two different models were analyzed for each of the tests. Each of these models was evaluated using three different methods. The resulting averages and ranges of values were compared with predicted results based upon previous tests and knowledge of the subsurface conditions at the two sites.

All pumping test results either fell within expected ranges or were reasonably close to expected values based upon professional judgement. While these confirming observations technically do not verify the results of the tests, they do support the probability of the original hypotheses being true.

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5. GROUNDWATER USE AT PIADC

In 1999, twelve functioning wells situated near the geographic center of Plum Island served all of PIADC's water supply needs. Excess pumped groundwater was stored in a 200,000 gallon water tower which sits atop the central highland. This high area is part of the Harbor Hill End Moraine.

PIADC production wells are located in two fields. Wells 1-10 comprise the Shallow Well Field and are, on average, about 30 feet deep. Wells 11-14 comprise the Deep Well Field and average about 60 feet in depth.

Pumping from the well fields usually occurred every other day. As a rule, one shallow and one deep well, or three shallow wells are pumped simultaneously (DePonte, 1999). This is to mitigate salinity increases caused by pumping the deeper wells at higher pumping rates.

Table 3.3 summarizes groundwater withdrawals for the years 1973 to 1999. Withdrawals are presented graphically in Figure 3.1. Annual totals are presented for most years. When data were available, monthly totals for January and July were also provided to illustrate any seasonal variability in water consumption. Large increases in July withdrawals in 1989, 1994 and 1998 are likely due to increased research activities, possibly associated with the Foreign Animal Disease (FAD) School.

5.1 Existing Well Information

Table 5.1 summarizes specifications on each production well and its associated pump. Boring logs, construction diagrams, and well acceptance test data forms for Wells 11-14 are presented in Appendix H. These wells were identified by the drillers as Wells 1-4, rather than 11-14. No well logs or construction diagrams for Wells 1-10 were available in PIADC files.

In 1999, Wells 1-10 contain 25-40 gallons per minute (gpm) pumps. Near term plans call for all 14 wells to contain these pumps by December 2000 (DePonte, 2000). At present (1999), Wells 13 and 14 have higher capacity (80-100 gpm) pumps.

At the time this Study was conducted, individual pumps were operated from the pump houses at each field. It was necessary to activate and deactivate each pump manually. Future plans for upgrading the wells called for the automation of the pumps by the end of 2000 which will allow them to be regulated through the use of timers. Currently (1999), the configuration of the control system only allows for 10 wells to be pumped at any one time without bypassing the treatment system. The limiting factor is the

Table 5.1:
PIADC Production Well Specifications

Well #	Casing Material	Casing Diameter (in)	Total Depth (ft)	Screened Interval (ft bgs)	Screen Material	Screen Diameter (in)	Slot size (in)	Pump Type and Size	Rating
Shallow Well Field									
1	W. I.	8	~30	~20-30	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
2	W. I.	8	~34	~24-34	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
3	W. I.	8	~32	~22-32	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
4	W. I.	8	~29	~19-29	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
5	W. I.	8	~30	~20-30	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
6	W. I.	8	~29	~19-29	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
7	W. I.	8	~29	~19-29	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
8	W. I.	8	~29	~19-29	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
9	W. I.	8	~27	~17-27	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
10	W. I.	8	~28	~18-28	Type 304 Stainless Steel	6 5/8 i.d. 7 1/2 o.d.	0.025	4-in. Myers submersible	25-40 gpm
Deep Well Field									
11	Galvanized W. I.	8	56	46-56	Bronze	6 5/8 i.d. 7 1/2 o.d.	0.025	No pump (will be 4-in. Myers submersible)	N/A
12	Galvanized W. I.	8	56.5	46.5-56.5	Bronze	6 5/8 i.d. 7 1/2 o.d.	0.025	No pump (will be 4-in. Myers submersible)	N/A
13	Galvanized W. I.	8	57.5	47.5-57.5	Bronze	6 5/8 i.d. 7 1/2 o.d.	0.025	Peerless vertical turbine pump (will be 4-in. Myers submersible)	80-90 gpm
14	Galvanized W. I.	8	57.17	47.17-57.17	Bronze	6 5/8 i.d. 7 1/2 o.d.	0.025	Peerless vertical turbine pump (will be 4-in. Myers submersible)	80-90 gpm

capacity of the two transfer pumps located in the vicinity of Building 59. All pumps could be pumped simultaneously if the treatment system were bypassed, and the water fed directly into the distribution system.

5.2 Water Treatment

During the Study period, all groundwater withdrawn from the supply wells passed through the treatment system located at Building 59. The raw water was treated with lime and chlorine prior to introduction into the distribution system. Only excess water that is withdrawn but not used during the course of a day is sent to the water storage tower. This includes virtually all of the water that is pumped at night.

5.3 Distribution System

Treated water is distributed about the island through a variety of 4" cement and 8", 10" and 12" cast iron pipes. General plans of the water distribution system are presented in Appendix I. Note that many of the lines on the northeastern portion of the island have been removed from service.

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6. FUTURE PIADC WATER USE

At the time the Study was initiated, plans for expanding the research facilities at Plum Island to Bio-Safety Level 4 (BSL-4) status were under consideration. Since that time, the BSL-4 concept has been abandoned, but upgrades to the existing BSL-3 facility infrastructure are anticipated to begin in 2008. These upgrades are intended to extend the operational life of PIADC until a new replacement animal disease center is constructed and "on-line". This new facility, however, is not expected to be constructed on Plum Island.

In light of the anticipated growth of PIADC, USDA-ARS requested that development scenarios be created to gauge the impact construction would have, regardless of BSL "rating" or status, on existing potable water resources. The basic assumptions provided by USDA-ARS for these scenario exercises called for a 50% expansion of PIADC's physical plant and a 50% increase in water needs (Payne, 2000). Recent water withdrawals have averaged 70,000 gpd. An increase of 50% means an average water use of 105,000 gpd after expansion. A modified value of 110,000 gpd was used for daily expanded use calculations. This is approximately equal to a 50% increase over the 1998 daily average.

Note that the predicted future average withdrawal of 110,000 gpd is well below the target safe yield of 150,000 gpd (See Section 3). However, it will still be important to monitor chloride levels in existing wells and to consider the installation of sentry wells to monitor the saltwater-fresh water interface.

Three different scenarios for withdrawing the necessary 110,000 gpd are presented below, based on the following supplemental supporting assumptions:

1. A maximum of 10 wells may be pumped at any one time.

2. All wells contain 25-40 gpm Myers pumps.

3. The pumps in the shallow wells operate at 40 gpm, while those in the deep wells operate at 25 gpm. The shallow well pump rate is based on averages for 1999. The deep well pumps currently average 85 gpm, but replacement is planned.

4. It is necessary to pump one shallow well for every deep well to dilute chloride levels in the mixed water. This may not be necessary when smaller pumps are installed in the deep wells.

6.1 Scenario 1 - What well configurations would produce 110,000 gallons <u>each and every day</u>?

A production rate of 110,000 gpd is equivalent to approximately 76 gpm over the course of 24 hours. Pumping 1 deep and one shallow well for 24 hours would produce about 93,600 gallons. Pumping 2 shallow wells would produce 115,200 gallons. Pumping 1 deep and 2 shallow wells would produce 151,200 gallons. Alternating different combinations of two and three wells could easily produce the required amount of water.

6.2 Scenario 2 - What well configurations would produce 220,000 gallons <u>every other day</u>?

Currently, pumping occurs at Plum Island on alternating days. If this practice is to be continued, an average of 220,000 gallons will have to be withdrawn during pumping days. The 200,000 gallon capacity of the storage tower would not be a limiting factor, since about half of the withdrawn groundwater would go directly to distribution and be consumed. If 1 deep well and 3 shallow wells are operated simultaneously, 208,800 gallons would be produced in 24 hours. Pumping 4 shallow wells would produce 230,400 gallons in 24 hours. Alternating different combinations of four wells could easily produce the required amount of water.

6.3 Scenario 3 - What well configurations would produce 220,000 gallons in <u>8 hours</u>? <u>10 hours</u>?

In case it ever became necessary or desirable to operate the well pumps only during business hours or some other portion of the day, scenarios were evaluated for producing the necessary 220,000 gallons during 8 and 10 hour periods, every other day.

The required 220,000 gallons could not be produced in eight hours. It would be necessary to pump all 10 shallow wells and 3 of the deep wells in order to produce 228,000 gallons. Currently, only 10 wells can be operated simultaneously without bypassing the treatment system. However, if the pumping period is increased to 10 hours, 10 wells can produce the necessary amount of water. Pumping 9 shallow wells and 1 deep well would produce 231,000 gallons in 10 hours. Pumping 10 shallow wells would produce 240,000 gallons in 10 hours.

6.4 Conclusions

The predicted expanded water use of 110,000 gpd can easily be met with the existing well and pump network. In fact, this rate has been achieved in the past. Water use during the period of 1978 to 1982 averaged 102,000 gpd to 110,000 gpd. This is well below the target safe yield of 150,000 gpd.

7. INCREASING FIREFIGHTING CAPACITY

Intense firefighting activities can empty the 200,000 gallon water storage tank in under two hours, and the tank is unlikely to be full in time of need. Five scenarios were developed in 1999 to increase firefighting capacity at Plum Island. These scenarios continue to be valid options as of the date of this report. All calculations were based on the following assumptions:

1. A maximum of 150,000 gallons of groundwater may be withdrawn in a single day. In fact, overpumping the aquifer during a fire emergency would be unlikely to have any detrimental effect. Crandell (1962) estimates total available groundwater in storage at 2,800,000,000 gallons.

2. A total of 110,000 gallons is withdrawn each day for general use. This leaves an additional 40,000 gpd that might be withdrawn for emergency use storage. At this rate, the 1,000,000 gallon Army era reservoir could be filled by pumping one additional pump continuously for 17-25 days.

3. Firefighting activities are assumed to consume 2,500 gallons per minute (gpm).

Estimated costs that might be associated with any of the scenarios are presented in Appendix C, Table C.2.

7.1 Scenario 1 - Full reservoir linked directly to hydrants

If the Army reservoir and its fire pump were renovated to permit storage of 1,000,000 gallons of non-potable water, and a hydrant system completely separate from the existing potable water system were installed, continuous firefighting capacity would increase to 6.7 hours. The reservoir would need to be renovated to potable standards if it were to remain connected to the existing potable system. Alternatives would be to connect the reservoir to its own distribution system (piping and hydrants) or to connect it to the potable system, but only release non-potable water from the reservoir in the event of an emergency.

If renovating the existing reservoir proved impractical, a new reservoir might be installed.

7.2 Scenario 2 - Wells only

Assuming any shallow well produces water at 40 gpm, a total of 63 wells would be needed to produce the necessary 2,500 gpm. Increasing the number of wells or the pumping capacities of existing wells is not a feasible alternative to increase firefighting capabilities.

7.3 Scenario 3 - Add one 200,000 gallon water tower; always keep one full

At the beginning of firefighting activities, the full tower would be pumped at a rate of 2,500 gpm. At the same time, 10 shallow wells would begin adding to the towers at a rate of 400 gpm. The worst case situation would involve a fire starting when one tower was full and the other practically empty. In 1.3 hours, the full tower would be emptied at 2,500 gpm. The second tower would contain 32,000 gallons at this point. The final result is approximately 1.6 hours of firefighting capacity.

Alternatively, the same results could be obtained if the existing 200,000 gallon tower were replaced with a 400,000 gallon tower.

7.4 Scenario 4 - Second tower is always a minimum of half-full

At the start of a fire, 300,000 gallons of water would be available. Using this water at 2,500 gpm and replenishing the supply at 400 gpm (10 wells) would provide 2.3 hours of firefighting capacity.

7.5 Scenario 5 - Link existing saltwater pumping system to hydrants

In 1999, three saltwater pumps were located in the harbor area of Plum Island. At one time, the pumps supplied water to be used for heat exchange purposes in Building 101's air conditioning system. At the time this Study was undertaken, they had been out of operation for about one year. Each pump had an operational capacity of approximately 5,000 gpm. The existing hydrant system could have been tied into the 12" pipeline running from these pumps to Building 101. This option would provide continuous firefighting capacity. If a pumper truck were used, saltwater might cause irreparable damage to the truck, but this may be an acceptable sacrifice in the event of a major fire. Alternatively, it might be desirable to have interior sprinkler systems within Building 101 run off of the potable system to avoid damage to sensitive laboratory equipment. Supporting exterior hydrants could be connected to the saltwater system. If an emergency did require the use of saltwater, the system could subsequently be flushed with freshwater to minimize any damage to piping.

7.6 Conclusions

Significant increases in firefighting capacity could be achieved through use of the Army era reservoir and/or the existing saltwater pump system. Bringing the existing reservoir and associated fire pump online, or installing a new 1,000,000 gallon reservoir and pump, would provide over six hours of continuous firefighting. It is hard to envision a situation where this would not be enough water. A combination of the reservoir and the saltwater pumps might be ideal, with the saltwater system being a worst case backup. In any case, changes would need to be made to the current water delivery system. If the existing reservoir were to be used, it would need to be renovated to potable standards, connected to a completely separate system, or only used in emergencies.

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8. WELLHEAD PROTECTION ASSESSMENT

The 1986 Amendments to the Safe Drinking Water Act established the Federal Wellhead Protection Program. The 1996 Amendments to the Safe Drinking Water Act placed even greater emphasis on prevention by creating the Source Water Protection Program (EPA, 1997). The following assessment loosely conforms with the methodology set forth in the EPA's State Source Water Assessment and Protection Programs - Final Guidance (1997). A Wellhead Protection Area (WHPA) is established, potential contamination sources are identified, and the susceptibility of the WHPA is assessed.

8.1 Classification of Groundwater

EPA has established the following classes of groundwater based on current or potential use:

1. **Class I: Special Ground Waters.** The protection of this groundwater is a top priority based upon its being a sole-source drinking water supply to a substantial population or a critical water source for a sensitive ecosystem.

2. **Class II: Ground Waters with Beneficial Uses.** Class II groundwater is less critical than Class I, but may be used for drinking water or other important uses, such as irrigation.

3. **Class III: Ground Waters of Limited Beneficial Use.** This groundwater has no potential for use as drinking water and little potential for other beneficial uses due to naturally high mineral levels or anthropogenic contamination that cannot feasiblely be remediated using current technology (Watson, 1995).

For the purposes of this study, the groundwater in the sole-source aquifer underlying Plum Island is considered Class I: Special Ground Waters.

8.2 The Wellhead Protection Areas (WHPAs)

WHPAs are established to prevent contamination of water supplies. Delineation of a WHPA begins with the identification of the Zone of Influence (ZOI) and the Zone of Contribution (ZOC). The ZOI is the area covered by the cone of pumping depression in each wellfield (based on the pumping test results discussed in Section 3). The ZOC is the entire recharge area of the wellfield, taking into consideration groundwater drainage divides. Often, when the water table is relatively flat, the ZOI and ZOC are considered equal. Finally, Zones of Transport (ZOTs) are delineated. These subzones are activity-controlled areas based on groundwater travel times and/or contaminant attenuation models.

One Wellhead Protection Area (Figure 8.1) was established covering both wellfields at PIADC. This is appropriate because the Zones of Transport and the Zones of Contribution for the two wellfields overlap. Zones of Influence were considered to be circles, 75-feet in radius, around each well. This is based on the results of the aquifer tests and assumes each well will contain a pump rated at 25-40 gpm. The Zones of Contribution for each wellfield are the areas generally found hydraulically upgradient from each field; that is, in the directions of and terminating at each of the adjacent groundwater divides.

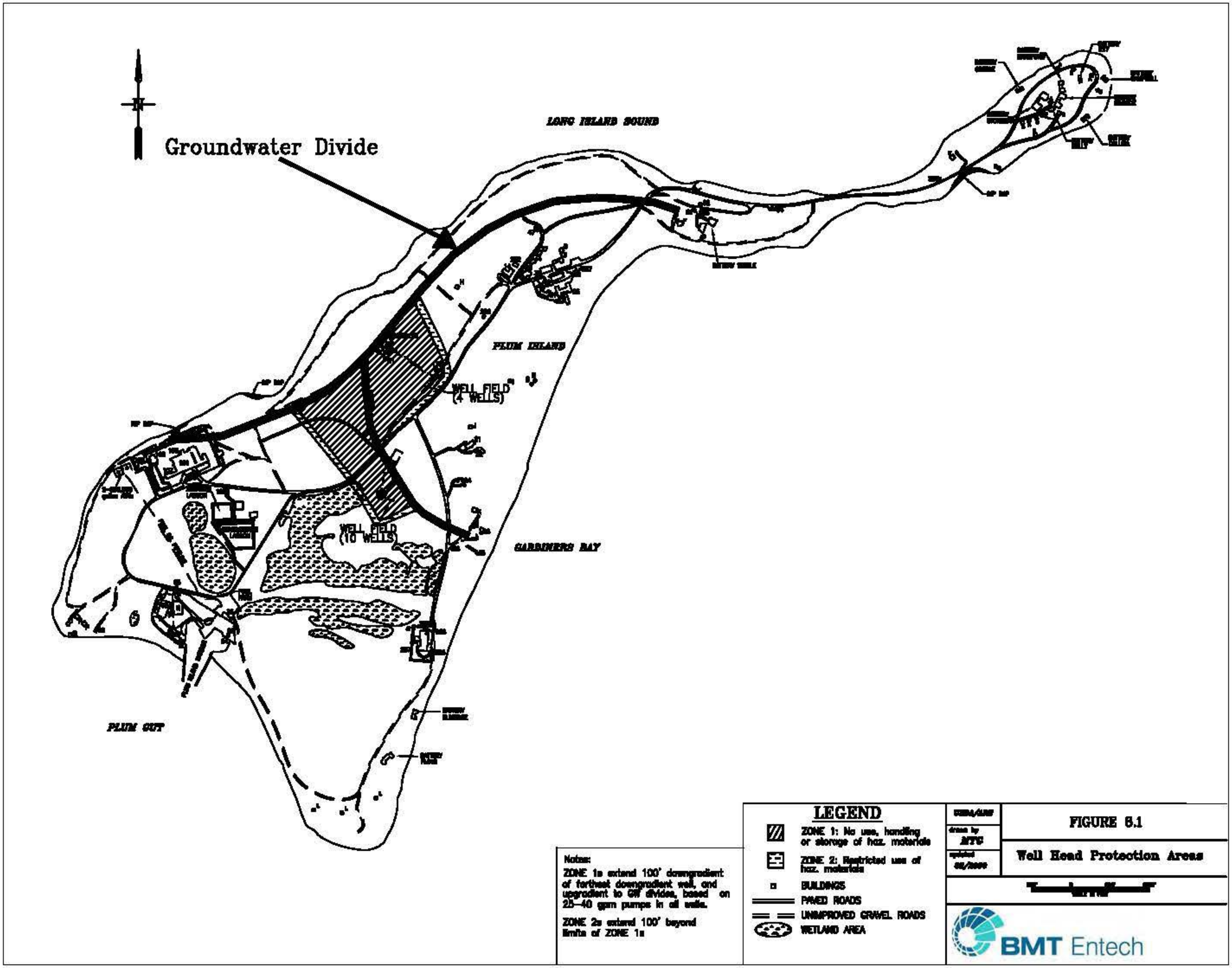
Groundwater travel times were used in the development of the Zones of Transport. A typical ZOT 1, the zone of highest use-restriction, extends to the 30-day groundwater travel time limit around a wellhead. In this Study, that approach would result in ZOT 1s extending from 17 to 90 feet from the wellfields, based on the travel times established during the aquifer tests. The fastest of these travel times (90 feet in 30 days) was adopted for this study, and rounded to 100 feet. Each of the ZOT 1's extends 100 feet hydraulically downgradient of the well farthest downgradient from either the central groundwater divide or the southern extension of the central divide.

The ZOT 2s extend 100 feet farther downgradient of the limits of the ZOT 1s (Figure 8.1).

8.3 Land Use Restrictions

The purpose of establishing Zones of Transport is to identify areas where the use of hazardous materials should be restricted, so as to prevent potential contamination of the potable groundwater supply. The following general use restrictions are recommended for the ZOTs:

> *Zone of Transport 1: No use, handling or storage of hazardous materials.* A significant chemical release in this area would be a serious threat to the quality of the water being withdrawn from the well fields. The installation of any underground storage tanks (USTs) should be avoided. Aboveground tanks (ASTs) should also be avoided. The goal of establishing a ZOT 1 is to create an environment of extremely low threat in the immediate vicinity of the supply wells. Other practices that should be avoided in this area are the application of sewage treatment sludges, the use of pesticides and the through-traffic of hazardous materials. Wastewater and drinking water treatment processes at the Building 59 area must be exempted from this rule. However, these processes should be closely monitored for any sign of potential contaminant release.
>
> *Zone of Transport 2: Restricted use of hazardous materials.* A very significant chemical release in ZOT 2 could seriously impact the well fields. Groundwater travel times from this zone to the water supply wells are estimated to be 30 days or more. However, the sandy soils of Plum Island would be unlikely to promote considerable natural degradation of a contaminant. The restrictions



N
Groundwater Divide
LONG ISLAND SOUND
PLUM ISLAND
WELL FIELD
(4 WELLS)
WELL FIELD
(10 WELLS)
GARDINERS BAY
PLUM GUT
LEGEND
ZONE 1: No use, handling or storage of haz. materials
ZONE 2: Restricted use of haz. materials
BUILDINGS
PAVED ROADS
UNIMPROVED GRAVEL ROADS
WETLAND AREA
Notes:
ZONE 1a extend 100' downgradient of farthest downgradient well, and upgradient to GW divides, based on 25–40 gpm pumps in all wells.
ZONE 2a extend 100' beyond limits of ZONE 1a
FIGURE 6.1
Well Head Protection Areas
BMT Entech

for use of this area should be similar in kind, but not degree, to those for ZOT 1. For instance, ASTs might be permitted in this area if they include proper secondary containment structures. Also, vehicles carrying significant quantities of hazardous materials might be routed around ZOT 1, and through ZOT 2.

8.4 Potential Sources of Groundwater Contamination

Section 1453 of the Safe Drinking Water Act, suggests, but does not require, that states inventory potential sources of contamination (EPA, 1997). In the same vein, PIADC should be aware of the different types of contamination sources that are present on Plum Island.

A number of general potential contamination sources have been identified on Plum Island. Most are outside of the WHPA. The establishment and maintenance of the WHPA is the major component in the protection of PIADC's water supply. However, general strategies for managing all potential contamination sources should be developed. In most cases, management strategies will simply involve the sharing of information between different PIADC facilities and water plant personnel.

The following categories of potential sources of groundwater contamination have been identified at Plum Island.

- *Animal operations*. The use of animals in research produces waste products that may be considered hazardous materials. All manure contains nitrates, phosphates and bacteria. At PIADC, the potential for research-related microorganisms must be considered, as well. While phosphates and bacteria are often easily attenuated in soils, nitrates are not. As nitrates are highly water-soluble, they constitute the portion of the manure that is most likely to pose a threat to groundwater (Patrick, 1987).

- *Atmospheric deposition*. The proximity of several urban areas to PIADC suggests a slight potential for groundwater contamination through the deposition of dry, soluble contaminants dissolved in precipitation. Sulfates and nitrates produced in cities travel through the atmosphere as fine particulates (< 1 micrometer) and are deposited as "acid rain." (Boubel, 1994)

- *Lagoons.* Waste management units associated with PIADC wastewater treatment plant could have an impact on ground water if chronic releases were to occur.

- *Dredge spoils*. The waste material of dredging operations in Plum Gut or other waterways might pose a contamination threat if it were deposited on Plum Island.

- *Septic systems*. Septic systems, by design, impart waste materials to subsurface soils. Due to the high permeability of the soils at Plum Island, waste from septic systems could, conceivably, impact the surficial aquifer from which PIADC's water is withdrawn.

- *Sewers*. Sewer leaks or breaks are potential sources of groundwater contamination.

- *WMAs, AOPCs*. The Waste Management Areas (WMAs) and Areas of Potential Concern (AOPCs) addressed in the CERCLA investigation may prove to be sources of groundwater contamination. The potential impacts of these sites will be further developed when the CERCLA investigation has been completed.

- *Underground Storage Tanks*. Underground storage tanks always pose some risk to groundwater.

- *Harbor operations (in-water and on-land releases)*. Fuel or chemical releases associated with fueling, servicing and general operation of boats could, indirectly, contaminate groundwater via surface water or soils.

- *Fuel and chemical spills (historic and potential)*. Historic, unremediated releases to surface soils can act as sources for groundwater contamination. Any future spill also has the potential to impact groundwater.

8.5 Known Areas of Groundwater Contamination

A complete inventory of known areas of groundwater contamination can and should be developed once the CERCLA and RCRA programs have been completed. Currently, the following five areas are known or suspected to have contaminated groundwater (Figure 8.2):

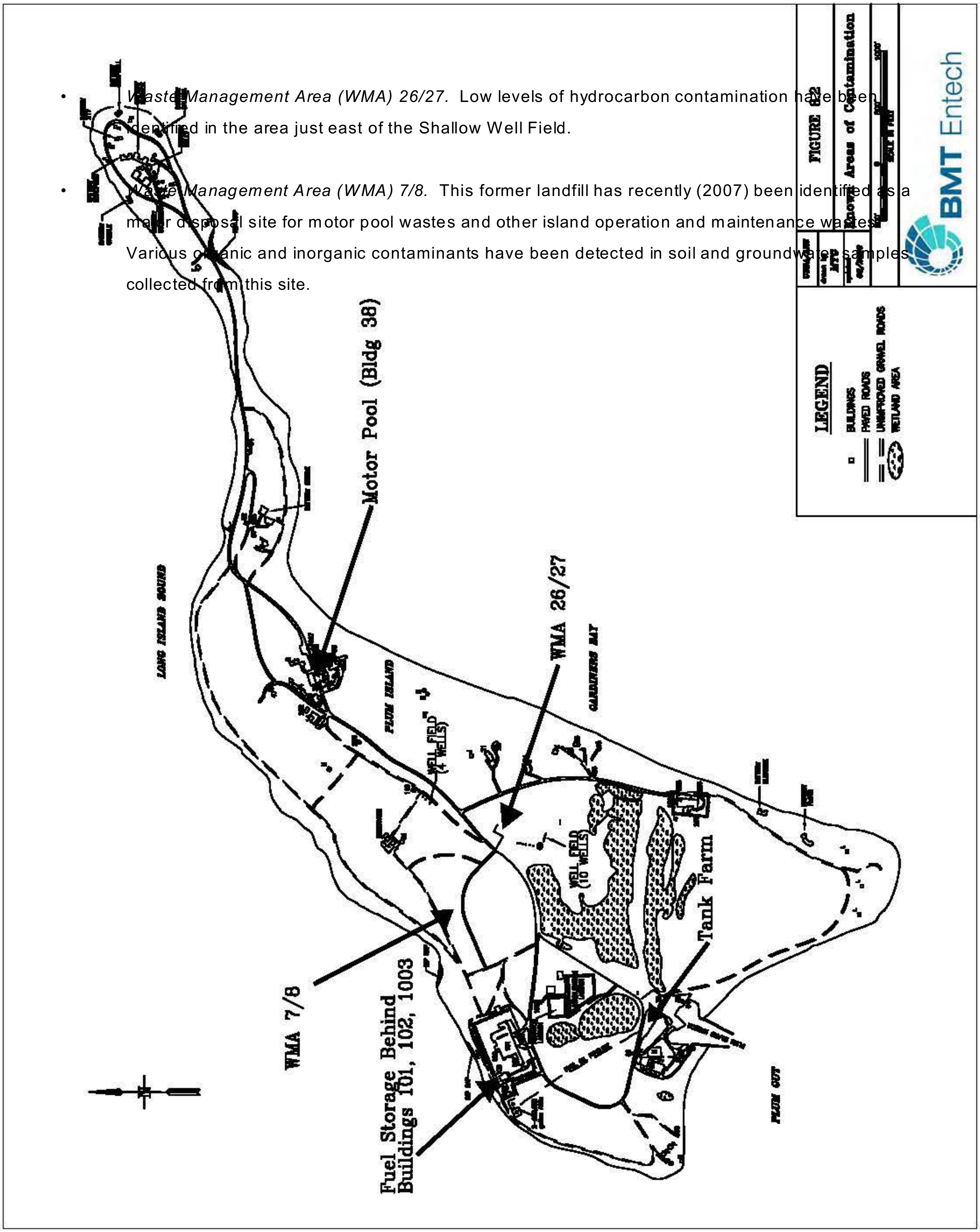
- *Fuel storage installation behind Buildings 101, 102 and 103.* A free petroleum product plume is located in this area.

- *Motor Pool (Building 38)*. During the RCRA investigation, soils behind Building 38 were found to be contaminated with petroleum product.

- *Tank farm in harbor area*. Currently, groundwater contains low levels of dissolved phase petroleum product.

- *Waste Management Area (WMA) 26/27.* Low levels of hydrocarbon contamination have been identified in the area just east of the Shallow Well Field.

- *Waste Management Area (WMA) 7/8.* This former landfill has recently (2007) been identified as a major disposal site for motor pool wastes and other island operation and maintenance wastes. Various organic and inorganic contaminants have been detected in soil and groundwater samples collected from this site.



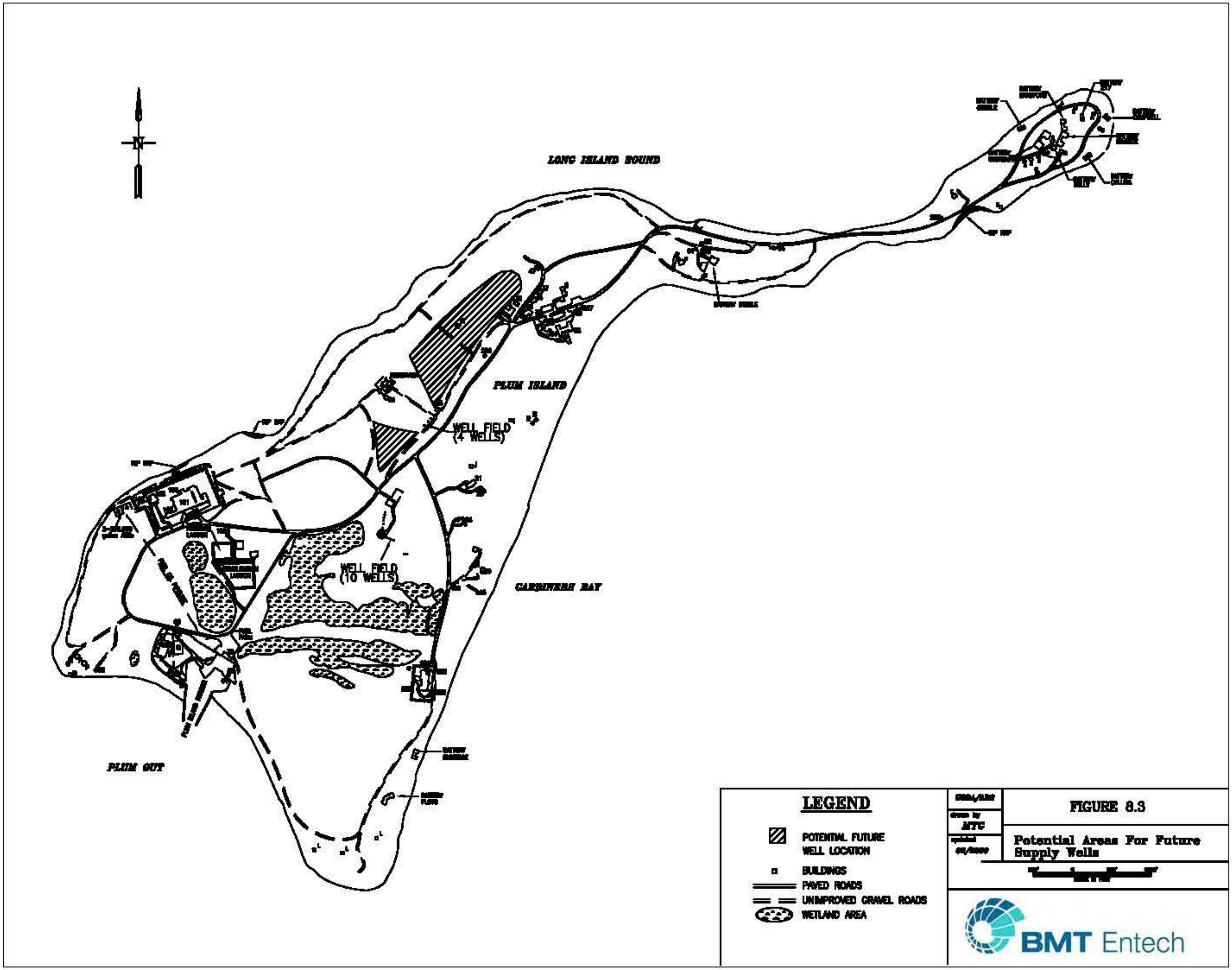
8.6 Susceptibility of WHPA

The purpose of inventorying possible contamination sources is to gauge the risk of any particular source impacting the WHPA. A complete susceptibility analysis can and should be performed when the CERCLA and RCRA programs have been completed.

8.7 Water Supply Areas for Future Expansion

If facility expansion results in an increase in water use of 50% over current levels, no additional wells will be necessary. However, further expansion may require the installation of additional wells. Any new wells should be placed in the central portion of the island, where the freshwater lens is thickest. This means expanding the Deep Well Field to the northeast or to the southwest (Figure 8.3). The WHPA already covers the area between the existing well fields, so this would be the logical place to site new wells.

Care should be taken to limit well interference when siting new wells. Wells should be aligned with recharge features (the nearest groundwater divide) and spaced appropriately based on their predicted pumping radii of influence. The area between the Shallow Well Field and the central groundwater divide should be avoided. Wells placed in this area would intercept recharge water needed by the shallow wells.



N
LONG ISLAND SOUND
PLUM ISLAND
WELL FIELD
(4 WELLS)
WELL FIELD
(10 WELLS)
GARDINERS BAY
PLUM GUT
LEGEND
POTENTIAL FUTURE
WELL LOCATION
BUILDINGS
PAVED ROADS
UNIMPROVED GRAVEL ROADS
WETLAND AREA
MTC
FIGURE 8.3
Potential Areas For Future
Supply Wells
BMT Entech

9. SUMMARY OF DRINKING WATER REGULATIONS

The Suffolk County Department of Health Services (SCDHS) has classified PIADC as a “Non-transient Non-community Public Water Supplier” (Van De Water, 1996). As a result, PIADC is required to meet the monitoring and reporting requirements of the federal Safe Drinking Water Act. The required water quality parameters and sampling schedule established by the SCDHS are presented in Table 9.1. All analytical results for sampling conducted in 1999 are provided in Appendix J.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
Inorganics			
lead	semi-annually	source and distribution	Semi-annual sampling will continue until concentrations are below action level of 0.015 mg/L.
copper	semi-annually	source and distribution	Semi-annual sampling will continue until concentrations are below action level of 1.3 mg/L.
nitrate	annually	distribution	Quarterly sampling is required for any well where concentration exceeds 50% of nitrate MCL of 10 mg/L.
pH	annually	distribution	
chloride	annually	distribution	
iron	annually	distribution	
manganese	annually	distribution	
sodium	annually	distribution	
arsenic	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
barium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
cadmium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
chromium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
fluoride	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
mercury	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
selenium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
antimony	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
beryllium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
cyanide	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
nickel	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
sulfate	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
Inorganics, continued			
thallium	triennially*	each well	*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years.
nitrite	triennially*	each well	1)*One sample must be collected from each well within 3 years of last sampling by 12/31/01 - thereafter, once every 3 years. 2)Quaterly sampling is required for any well where concentration exceeds 50% of MCL of 1 mg/L.
Microbiologicals			
Total coliform	quarterly	distribution	
Escherichia coli	*	*	*Collect for all positive coliform samples.
Principal Organic Contaminants			
vinyl chloride	annually	each well	Sample quarterly if detected.
benzene	annually	each well	Sample quarterly if detected.
bromobenzene	annually	each well	Sample quarterly if detected.
bromochloromethane	annually	each well	Sample quarterly if detected.
bromomethane	annually	each well	Sample quarterly if detected.
n-butylbenzene	annually	each well	Sample quarterly if detected.
sec-butylbenzene	annually	each well	Sample quarterly if detected.
tert-butylbenzene	annually	each well	Sample quarterly if detected.
carbon tetrachloride	annually	each well	Sample quarterly if detected.
chlorobenzene	annually	each well	Sample quarterly if detected.
chloroethane	annually	each well	Sample quarterly if detected.
chloromethane	annually	each well	Sample quarterly if detected.
2-chlorotoluene	annually	each well	Sample quarterly if detected.
4-chlorotoluene	annually	each well	Sample quarterly if detected.
dibromomethane	annually	each well	Sample quarterly if detected.
1,2-dichlorobenzene	annually	each well	Sample quarterly if detected.
1,3-dichlorobenzene	annually	each well	Sample quarterly if detected.
1,4-dicchlorobenzene	annually	each well	Sample quarterly if detected.
dichlorodifluoromethane	annually	each well	Sample quarterly if detected.
1,1-dichloroethane	annually	each well	Sample quarterly if detected.
1,2-dichloroethane	annually	each well	Sample quarterly if detected.
1,1-dichloroethene	annually	each well	Sample quarterly if detected.
cis-1,2-dichloroethene	annually	each well	Sample quarterly if detected.
trans-1,2-dichloroethene	annually	each well	Sample quarterly if detected.
1,2-dichloropropane	annually	each well	Sample quarterly if detected.
Principal Organic Contaminants, continued			
1,3-dichloropropane	annually	each well	Sample quarterly if detected.
2,2-dichloropropane	annually	each well	Sample quarterly if detected.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
1,1-dichloropropene	annually	each well	Sample quarterly if detected.
cis-1,3-dichloropropene	annually	each well	Sample quarterly if detected.
trans-1,3-dichloropropene	annually	each well	Sample quarterly if detected.
hexachlorobutadiene	annually	each well	Sample quarterly if detected.
isopropylbenzene	annually	each well	Sample quarterly if detected.
isopropyltoluene	annually	each well	Sample quarterly if detected.
methylene chloride	annually	each well	Sample quarterly if detected.
n-propylbenzene	annually	each well	Sample quarterly if detected.
ethylbenzene	annually	each well	Sample quarterly if detected.
styrene	annually	each well	Sample quarterly if detected.
1,1,1,2-tetrachloroethane	annually	each well	Sample quarterly if detected.
1,11,2,2-tetrachloroethane	annually	each well	Sample quarterly if detected.
ttetrachloroethene	annually	each well	Sample quarterly if detected.
toluene	annually	each well	Sample quarterly if detected.
1,2,3-trichlorobenzene	annually	each well	Sample quarterly if detected.
1,2,4-trichlorobeenzene	annually	each well	Sample quarterly if detected.
1,1,1-trichloroethane	annually	each well	Sample quarterly if detected.
1,1,2-trichloroethane	annually	each well	Sample quarterly if detected.
trichloroethene	annually	each well	Sample quarterly if detected.
trichlorofluoromethane	annually	each well	Sample quarterly if detected.
1,2,3-trichloropropane	annually	each well	Sample quarterly if detected.
1,2,4-trimethylbenzene	annually	each well	Sample quarterly if detected.
1,3,5-trimethylbenzene	annually	each well	Sample quarterly if detected.
m-xylene	annually	each well	Sample quarterly if detected.
o-xylene	annually	each well	Sample quarterly if detected.
p-xylene	annually	each well	Sample quarterly if detected.
methyl-tert-butyl-ether	annually	each well	Sample quarterly if detected.
Total trihalomethanes	N/A	N/A	Not required if chlorination waiver is maintained.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
Secondary Organic Contaminants and Pesticides			
alachlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
aldicarb	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
aldicarb sulfoxide	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
aldicarb sulfone	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
atrazine	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
carbofuran	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
chlordane	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
dibromchloropropane	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
2,4-D	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
endrin	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
ethylene dibromide	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
Secondary Organic Contaminants and Pesticides, continued			

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
heptachlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
heptachlor epoxide	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
lindane	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
methoxychlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
polychlorinated biphenyls	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
pentachlorophenol	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
toxaphene	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
2,4,5-TP (Silvex)	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
aldrin	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
benzo(a)pyrene	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
butachlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
Secondary Organic Contaminants and Pesticides, continued			
carbaryl	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
dalapon	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
di(2-ethylhexyl)adipate	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
di(2-ethylhexyl)phthalates	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
dicamba	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
dieldrin	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
dinoseb	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
diquat	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
endothall	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
glyphosate	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
hexachlorobenzene	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
Secondary Organic Contaminants and Pesticides, continued			
hexachlorocyclopentadiene	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
3-hydroxyxarbofuran	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.

Table 9.1:
Water Supply Monitoring Requirements

ANALYTE	FREQUENCY	LOCATION	NOTES
methomyl	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
metolachlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
metribuzin	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
oxamyl(Vydate)	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
propachlor	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.
simazine	triennially	each well	Quarterly sampling is required for any well where contaminant is detected or where a filter system has been installed for Secondary Organic Contaminants.

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APPENDIX A:

Pumping Test Results Letter

CDM-98038-050

TO: Elsa Payne, USDA-ARS Environmental Protection Specialist, PIADC

FROM: ENTECH, Inc.
Steve Maloney, Groundwater Study Task Manager

cc: Jeff Tuttle, PIADC CERCLA Project Manager
Rick McKenna, ENTECH Operations Manager

DATE: January 21, 2000

SUBJECT: Preliminary Pumping Test Results (to be included in Groundwater Study Report)

As one element of the CERCLA investigation at Plum Island Animal Disease Center (PIADC), PIADC asked ENTECH to update the island's 1983 groundwater survey (ERM, 1983).
As part of the update, ENTECH conducted 24-hour aquifer pumping tests at each of the two PIADC well fields. The purpose of the tests was to characterize the hydraulic properties of the upper glacial aquifer at Plum Island, and to determine whether either of the two well fields might potentially be affected by groundwater contamination originating from Waste Management Areas (WMAs) or Areas of Potential Concern (AOPCs).

Please refer to the definitions section on page 13 of this letter report for explanations of hydrologic terms used in the report.

The tests were conducted in November of 1999. Pumping test results show great internal consistency, and are indicative of a highly transmissive aquifer (88,000 - 122,000 gallons per day per foot [gpd/ft]). Average hydraulic conductivities (1,100 - 1,530 gpd/ft^2) are as would be expected in a coarse sandy aquifer (Heath, 1983). Average storativity values ($4x10^{-3}$ - $1x10^{-2}$) are somewhat lower than expected. This may be due to the presence of a great deal of fine sand in the pumping zones.

Distance-drawdown analyses estimating radius of cone of depression after 24 hours of pumping were performed for each of the well fields. The radius at the Old Well Field is estimated to be 170 feet. At the New Well Field, where smaller pumps are currently in use, the pumping radius is an estimated 70 feet.

	Hydraulic Conductivity		Transmissivity		Storativity		Radius of Cone of Depression
	Average	Range	Average	Range	Average	Range	
TEST 1 (Old Well Field: Wells 11-14) **Pumping Well #14** **Pumping Rate 83 gpm**	1,500 gpd/ft^2 7.10×10^{-2} cm/s	1,470-1,530 6.95×10^{-2}-7.24×10^{-2}	119,000 gpd/ft	117,000-122,000	1×10^{-2}	9.56×10^{-3}-$1.27 \text{-} 10^{-2}$	~170 ft
TEST 2 (New Well Field: Wells 1-10) **Pumping Well #9** **Pumping Rate 40 gpm**	1,200 gpd/ft^2 5.68×10^{-2} cm/s	1,100-1,260 5.20×10^{-2}-5.96×10^{-2}	95,000 gpd/ft	88,000-100,500	4×10^{-3}	3.30×10^{-3}-4.29×10^{-3}	~70 ft

Groundwater seepage velocities and travel times along three flow paths were estimated based upon the pumping test results. The flow paths, established by ERM (1983), all begin at the island's groundwater divide, and extend to the shoreline (see Figure 2-1, ERM, 1983). Velocity and travel time estimates are summarized below.

	Average Lateral Velocity (ft./day)	Travel Time
Flow Path A **Divide to North Shore**	3.0	225 days 0.62 years
Flow Path B **Divide to Southeast Shore**	1.3	1,200 days 3.3 years
Flow Path C **Southern Divide Extension to Southwest Shore**	0.56	6,604 days 18.1 years

The travel time calculations suggest that the fresh water lens beneath Plum island flushes completely within approximately 20 years.

A detailed presentation of the test procedures and discussion of results follows.

SITE DESCRIPTION

The aquifer tests were conducted at PIADC's two well fields which provide all drinking and process water for Plum Island. The "New Well Field", adjacent to Building 59, consists of ten wells, numbered 1 through 10. These wells are all approximately 25 feet deep, and contain pumps rated at 25-40 gallons per minute (gpm). The "Old Well Field", adjacent to Building

115, consists of four wells, numbered 11 through 14. These wells are all approximately 55 feet deep. Wells 13 and 14 contain pumps rated at 80-90 gpm. Wells 11 and 12 do not contain functioning pumps.

Geology and Hydrology of Plum Island

A Precambrian crystalline basement probably occurs at a depth of 600-700 feet below Plum Island. The bedrock is overlain by semi-consolidated and unconsolidated sediments of Cretaceous and Quaternary age. Directly atop the bedrock is the Raritan Formation. The sandy portions of the Raritan make an excellent aquifer on Long Island, but undoubtedly contain brackish or salt water beneath Plum Island. Above the Raritan lie the post-Raritan Cretaceous deposits of sand, gravel, silt and clay. Several post-Raritan units make good aquifers on Long Island, but also probably contain brackish or salt water beneath Plum Island.

The upper 200 to 300 feet of the island consists of Pleistocene glacial deposits. Sand and gravel predominate, with the entire thickness being saturated. A fresh water lens extends to an approximate depth of 100 feet in the center of the island. Crandell (1962) estimated this depth using the Ghyben-Herzberg method of multiplying the thickness of a freshwater lense above sea level by 40 to obtain its thickness below sea level. The maximum elevation of the water table is approximately 2.5 feet above sea level in the center of Plum Island.

During a period of ice retreat and stagnation, till material that made up the central portion of the island was scoured out and filled with outwash material. All of the water supply wells at Plum Island are screened in these outwash sands and gravels (Crandell, 1962).

Previous Investigations at Plum Island and Vicinity

The only aquifer tests known to have been performed on Plum Island were the 1964 well acceptance tests of Wells 11-14. Many tests have been performed on the upper glacial aquifer of Long Island, which is the same unit found beneath Plum Island (McClymonds, 1972).

Current Use

The twelve functioning wells at Plum Island supply all of PIADC's water by filling a 200,000 gallon storage tower which sits atop the central highland. This high area is, in fact, the Harbor Hill End Moraine, and represents one of the stagnation points of the Wisconsin ice sheet.

Pumping from the well fields usually occurs every other day. As a rule, one shallow and one deep well, or three deep wells are pumped simultaneously (DePonte, 1999). This is to mitigate salinity increases caused by pumping the deeper wells at higher pumping rates.

HYPOTHESES

A multiple-well aquifer pumping test provides data on the following aquifer characteristics: hydraulic conductivity, transmissivity, storativity and radius of cone of depression. Existing literature and the data generated during the 1964 well acceptance tests were consulted to develop expected ranges for these values.

Background Data

In reviewing the results of a number of aquifer tests on Long Island, McClymonds et al (1972) estimated the average hydraulic conductivity in the upper glacial aquifer at 1,700 gpd/ft^2. The average for north central Suffolk County, near Plum Island, was 1,500 gpd/ft^2.

The average transmissivity of the upper glacial aquifer was 200,000 gpd/ft in the McClymonds study. As part of the current investigation, transmissivity at Plum Island was estimated using the data from the Well #14 acceptance test. Depending on input parameters, the transmissivity estimate was between 35,000 and 40,000 gpd/ft. This method of determining transmissivity is considered much less reliable than an actual multiple well test. In fact, McClymonds found that well acceptance tests on Long Island consistently gave significantly lower transmissivities than those obtained from traditional multiple well tests.

Storativity data were not reported by McClymonds. In general, the storativity of an unconfined aquifer is equal to its specific yield, and ranges between $1x10^{-2}$ and $3x10^{-1}$ (Driscoll, 1986).

The well acceptance test at Well #14 made use of some ill-defined observation wells. For this reason, it is possible to estimate a radius for the cone of depression during the acceptance test at between 10 and 20 feet, at the pumped rate of 61 gpm.

Predicted Results

The McClymonds hydraulic conductivity average of 1,500 gpd/ft^2 for north central Suffolk County was chosen as a reasonable estimate based upon the proximity of the data points to Plum Island.

Transmissivity is equal to hydraulic conductivity multiplied by aquifer thickness. The aquifer thickness was estimated at 80 feet at each of the PIADC well fields, based upon Crandell (1962). This thickness multiplied by the predicted hydraulic conductivity of 1,500 gpd/ft^2 gives a product of 120,000 gpd/ft. While this is lower than the average McClymonds calculated for the upper glacial aquifer, the average aquifer thickness in the McClymonds study was 140 feet. An expected transmissivity of approximately 120,000 gpd/ft was deemed reasonable for this study.

The generally accepted range of storativity values for unconfined aquifers, $1x10^{-2}$ to $3x10^{-1}$, served as the expected range for this study.

The pumping radius for the Well #14 acceptance test was estimated at approximately 20 feet at 61 gpm. The pump that is currently installed in Well #14 was known to be pumping at a rate of 83 gpm before ENTECH began the aquifer tests at Plum Island. Because a gauge at the Pumphouse was not working prior to the tests, the pumping rate at Well #9 could not be determined with precision before the test. It was thought to be operating at 25-30 gpm. Based on these figures, general ranges were predicted for the pumping radii during the tests. The radius at the Old Well Field (#14) was predicted to be between approximately 25 and 35 feet. The radius at the New Well Field (#9) was predicted to be between 8 and 10 feet.

Conductivity at the Old Well Field

Pumping the deep wells at the Old Well Field at the rate of 80-90 gpm produces water of higher salinity than that taken from the New Well Field. The implication is that a saltwater intrusion cone rises below the pumping well, increasing the salt content of the pumped water. For this reason, conductivity levels in Observation Well B-6, 8 feet from the pumping well, were expected to rise during Test 1.

Boundary Conditions

The lateral extent of any particular glacial outwash lens is often quite limited in comparison to the size of the entire deposit of outwash. Zones of coarse, highly conductive material are usually surrounded by less conductive areas. For this reason, low-flow boundaries are commonly encountered at some point during a pumping test in glacial outwash (Driscoll, 1986). The result is an essentially instantaneous decrease in the slope of a time-drawdown plot of the test data.

As McClymonds does not report any instances of low-flow boundaries being encountered, no such conditions were expected in this study.

FIELD PROCEDURES

In September and October of 1999, eleven observation wells were installed at the production well fields. Their distances from the pumping wells were based upon the predicted drawdowns at each field.

Observation Well Installation at the New Well Field

Five observation wells were installed at the New Well Field (A-1 through A5). Boreholes were advanced using a truck-mounted Geoprobe^{tm} unit. The wells were constructed of 1" diameter PVC and built inside the 2 1/8" Geoprobe^{tm} rods. Screened intervals were approximately

15-25 feet bgs. This is the same interval screened in the pumping well, #9. The screen slot sizes are 0.010".

Observation Well	Distance From Pumping Well #9 (ft.)
A-1	3.5
A-2	6.8
A-3	10.3
A-4	16.8
A-5	30.8

Observation Well Installation at the Old Well Field

Six observation wells were installed at the Old Well Field (B-1 through B-6). Boreholes were advanced using a truck-mounted Simco 2800 drill rig equipped with 4 1/4" hollow-stem-augers. The wells were built inside the augers. Observation wells B-1 through B-5 were constructed of 1" PVC, while well B-6 was built using 3" PVC. Well B-6 was designed to accommodate a Troll 8000 data logger with a conductivity probe. All of the wells were screened at approximately 45-55 feet bgs. This is approximately the same interval at which the pumping well, #14, is screened. All screen openings are 0.010".

Observation Well	Distance From Pumping Well #14 (ft.)
B-1	4.8
B-2	10.7
B-3	18.1
B-4	32.6
B-5	62.7
B-6	8.0

Pressure Transducer Placement

Original work plans called for the use of six pressure transducers at each well field. Due to equipment failures, only four transducers were available for use at the Old Well Field. By the time of the test at the new Well Field, five working transducers were available.

Transducer Placement at the New Well Field

Transducers were set in Pumping Well #9 and Observation Wells A-1, A-2, A-4 and A-5. They were lowered to the bottom of each well, and then pulled up approximately one foot.

Transducer Placement at the Old Well Field

Transducers were set in Observation Wells B-1, B-2, B-3 and B-4. They were lowered to the bottom of each well, and then pulled up approximately one foot. It was not possible to place a transducer in Pumping Well #14 due to the design of its discharge assembly.

A Troll 8000 data logger was placed in the 3" well, B-6. Its purpose was to monitor any changes in groundwater conductivity during the pumping test. The Troll's conductivity probe was set at approximately 52 feet below ground surface.

Pumping Test 1 Procedure

The test at the Old Well Field was designated Test 1. The transducers and Troll were set in the wells on November 1, 1999, and allowed to equilibrate for approximately 24 hours. Water and conductivity levels during this pre-test were recorded in order to establish a baseline for the pumping test proper.

Pumping Test 1 began on November 2, 1999. Well #14 was turned on at 0910, and pumped continuously at 83 gpm until 0935 on November 3, 1999. Water level data were recorded until 1245. Water levels recovered to near static levels within approximately three hours. All water and conductivity level data were downloaded to a personal computer on the afternoon of November 3.

Pumping Test 2 Procedure

The test at the New Well Field was designated Test 2. The transducers were set in the wells on November 3, 1999, and allowed to equilibrate for approximately 18 hours. Water levels during this pre-test were recorded in order to establish a baseline for the pumping test proper.

Pumping Test 2 began on November 4, 1999. Well #9 was turned on at 0732, and pumped continuously at 40 gpm until 0620 on November 5, 1999. Water level data were recorded until 0900. The pump was turned off about one hour early because the water tower was overflowing. Water levels recovered to near static levels within approximately three hours. All water and conductivity level data were downloaded to a personal computer on the morning of November 5.

ANALYSIS OF TEST DATA

All pumping test data were analyzed using AquiferTest for Windows, version 2.55. Raw data were converted into Excel files, then imported into AquiferTest.

Each test was analyzed using three different methods: the standard Theis method (corrected for unconfined conditions), the Cooper and Jacob straight line method, and the Neuman method for unconfined aquifers.

Pre Test Water Levels

Water levels collected during the equilibration periods before each test were graphed and compared with tide data collected during the same periods at Montauk Point, Long Island, and New London, Connecticut. These comparisons showed no tidal influence on water levels at the well fields.

Test 1 Analysis

The Test 1 data (Old Well Field) were analyzed using two different sets of initial conditions. The first set of analyses excluded water level data collected from Observation Well B-1. This was done to exclude any vertical flow components of the well discharge from the data analysis. Such vertical flow in the vicinity of a pumping well often makes up a significant portion of discharge in Long Island's upper glacial aquifer (McClymond's, 1972). The second set of analyses used all water level data sets.

Test 2 Analysis

The Test 2 data (New Well Field) were also analyzed using two different sets of initial conditions. The first set of analyses used all water level data sets. The second excluded data from Observation Well A-1.

Determination of Groundwater Velocities and Travel Times

Groundwater seepage velocities were determined using the following relationship:

$$U=Ki/n,$$

where U = average groundwater velocity (ft/day)
K = hydraulic conductivity (gpd/ft^2)
i = hydraulic gradient (dimensionless)
n = effective porosity (dimensionless).

Velocities were calculated using the average hydraulic conductivity for Test 1, of 1,500 gpd/ft^2.

An effective porosity of 0.25 was estimated based upon observations of drill cuttings during well installation. The same hydraulic gradients estimated for each flow path in the ERM report (1983) were used in this study.

DISCUSSION

For each test, transmissivity and hydraulic conductivity values were determined by averaging the results of six analyses. The Theis, Cooper-Jacob, and Neuman solutions were calculated for each of two sets of initial conditions.

Storativity values were determined by averaging the results of two analyses. As only the Neuman analysis provides a storativity solution, it was the Neuman results, calculated for each of the two sets of initial conditions, that were averaged to determine storativity.

Test 1 Results

The two different models for Test 1 (with and without B-1 data) produced nearly identical results for hydraulic conductivity and transmissivity. The hydraulic conductivity average of 1,500 gpd/ft^2 is equal to the predicted value. The transmissivity average of 119,000 gpd/ft is practically equal to the predicted value of 120,000 gpd/ft.

The storativity average of $1x10^{-2}$ is equal to the low end of the range for a typical unconfined aquifer. This low value may be due to much of the aquifer above the screened interval being very fine sand. It may also be a result of only having two data points to average.

The radius of the cone of depression after 24 hours of pumping was approximately 170 feet. This is far greater than the predicted radius of 25-35 feet. Two reasons for this discrepancy are readily apparent. The first is the fact that the shallow portion of the aquifer consists of finer material than was initially anticipated. The second reason stems from the unreliable nature of well acceptance test data, particularly in the upper glacial aquifer of Long Island. It was well acceptance test data that provided the basis for the estimated pumping radius.

Analysis of time-drawdown data indicates no low-flow boundaries were encountered during pumping, as predicted.

Conductivity Probe Results

Conductivity of the water in Observation Well B-6 was expected to increase as a result of pumping. In fact, levels showed a slight decrease (~9%) during Test 1. The decrease may be a result of the well essentially being developed during the pumping test, with fine material being removed from the well's immediate vicinity. It may also be that pumping water across the conductivity probe actually causes a very slight change in the probe's ability to measure properly.

This scenario seems logical considering the fact that conductivity returned to pre-test levels immediately upon the cessation of pumping.

Two possible reasons are suggested for conductivity not *increasing* during the pumping test. The first is that the test may not have lasted long enough for salt water intrusion to occur. This seems unlikely, since the production wells are rarely pumped for more than 24 hours, yet salinity does increase. The second possibility is that the salt water intrusion cone rose up to the pump in Well #14, but did not extend far enough laterally to include the portion of Observation Well B-6 that contained the conductivity probe. This seems very likely, since the conductivity probe was at a depth equal to or, possibly, slightly shallower than the intake of the pump in Well #14. It is also likely that such an intrusion cone would be very steep in the coarse material that seems to underlie the well field.

Test 2 Results

Hydraulic conductivity and transmissivity calculations produced results over a slightly larger range in Test 2 than was the case for Test 1. This may indicate the presence of a slight vertical flow component to the drawdown at Observation Well A-1. Alternatively, it may just be a natural result of analyzing pumping test data in different ways.

The hydraulic conductivity average of 1,200 gpd/ft^2 is slightly lower than the predicted value of 1,500 gpd/ft. The transmissivity average of 95,000 gpd/ft is slightly lower than the predicted value of 120,000 gpd/ft. These results are likely due to the fact that the wells at the New Well Field are screened above the gravel unit. As a result, all of the water drawn from this field is drawn through fine sand, rather than the sand and gravel typical of screened intervals in the upper glacial aquifer, including the Old Well Field.

The storativity average of 4×10^{-3} is very low for an unconfined aquifer. This may be due to the fine nature of the material in the pumping zone and/or it may be a result of only having two data points to average.

The radius of the cone of depression after 24 hours of pumping was approximately 70 feet. This is far greater than the predicted radius of 8-10 feet. Three reasons for this discrepancy are readily apparent. The first is the fact that the actual pumping rate during the test was 40 gpm, not the 25-30 gpm that had been expected. Second, the wells at the new Well Field are entirely screened in fine sand. Prior to well installation, these wells were thought to be set in gravel. A fine sand would be expected to produce a larger cone of depression because of its lower hydraulic conductivity. Finally, well acceptance test data are known to be unreliable indicators of hydraulic properties, particularly in the upper glacial aquifer of Long Island.

Analysis of time-drawdown data indicates no low-flow boundaries were encountered during pumping, as predicted.

Validity of Test Results

Numerical models of natural systems, rather than being a collection of facts, are really a form of complex scientific hypothesis. They can never be verified (Oreskes, 1994). In particular, a pumping test represents a complex system where input parameters can never be known completely and the operational processes, themselves, are not entirely understood. Pumping test results are non-unique; that is, they can be produced by different sets of inputs. They may not be accurate in predicting future results.

However, pumping tests can be used to support the probability that a set of hypotheses is representative of reality. To do this, more than one model should be created using different initial conditions (Wuolo, 1993). The results can then be compared with original hypotheses.

In the current study, two different models were analyzed for each of the tests. Each of these models was evaluated using three different methods. The resulting averages and ranges of values were compared with predicted results based upon previous tests and knowledge of the subsurface conditions at the two sites.

All results either fell within expected ranges or were reasonably close to expected values based upon professional judgement. While these confirming observations technically do not verify the results of the tests, they do support the probability of the original hypotheses being true.

DEFINITIONS

Cone of depression: The depression of heads around a pumping well caused by the withdrawal of water.

Drawdown: The reduction in head at a point caused by the withdrawal of water from an aquifer.

Head (total head): The height above a datum plane of a column of water. In a groundwater system, it is composed of elevation head and pressure head.

Hydraulic conductivity: The capacity of a rock to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Specific Yield: The ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock.

Storativity (storage coefficient): The volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance.

Transmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.

(Heath, 1983)

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APPENDIX B:

Pumping Test Graphs

TEST 1 GRAPHS

TEST 1 CALCULATIONS

TEST 2 GRAPHS

TEST 2 CALCULATIONS

APPENDIX C:

General Cost Estimates

Table C.1:
Approximate Costs to Install Three Sentry Wells at Plum Island

ACTIVITY	COST	ASSUMPTIONS
Drilling costs		
Mobilization	$700	
Drilling	$3,700	6-inch hole/ 300 total feet/ 10 split-spoon samples
Installation	$4,300	250 feet of 2-inch Sch. 40 PVC/ concrete well pads with flush mounted covers
Well Development	$600	5 hours total
Geophysical costs		
Equipment	$2,300	
Geophysicist/geologist	$1,200	
TOTAL	**$12,800**	

Table C.2:
Selected Estimated Costs Associated With Water Distribution System Enhancements

ITEM	ESTIMATED COST, INSTALLED	NOTES
New 500,000 gallon insulated, heated, fiberglass ground tank	$150,000(1)	
New 1,000,000 gallon insulated, heated, fiberglass ground tank	$300,000(2)	
New foundation for ground tank	$25,000(1)	
New fire pump	$25,000(1)	
New pumphouse	$20,000(1)	
Altitude valve set-up	N/A	
Dismantle existing water tower	$100,000(1)	possible LBP, asbestos waste
New 200,000 gallon elevated toro water tower	$400,000(2)	
400,000 gallon elevated toro water tower	$600,000(1)	
Renovate existing groundtank	N/A	
Install geodesic dome	N/A	

Notes:
1) Garber, 2000
2) Estimated based on Garber's figures for similar structures of different sizes
N/A: Not available

APPENDIX D:

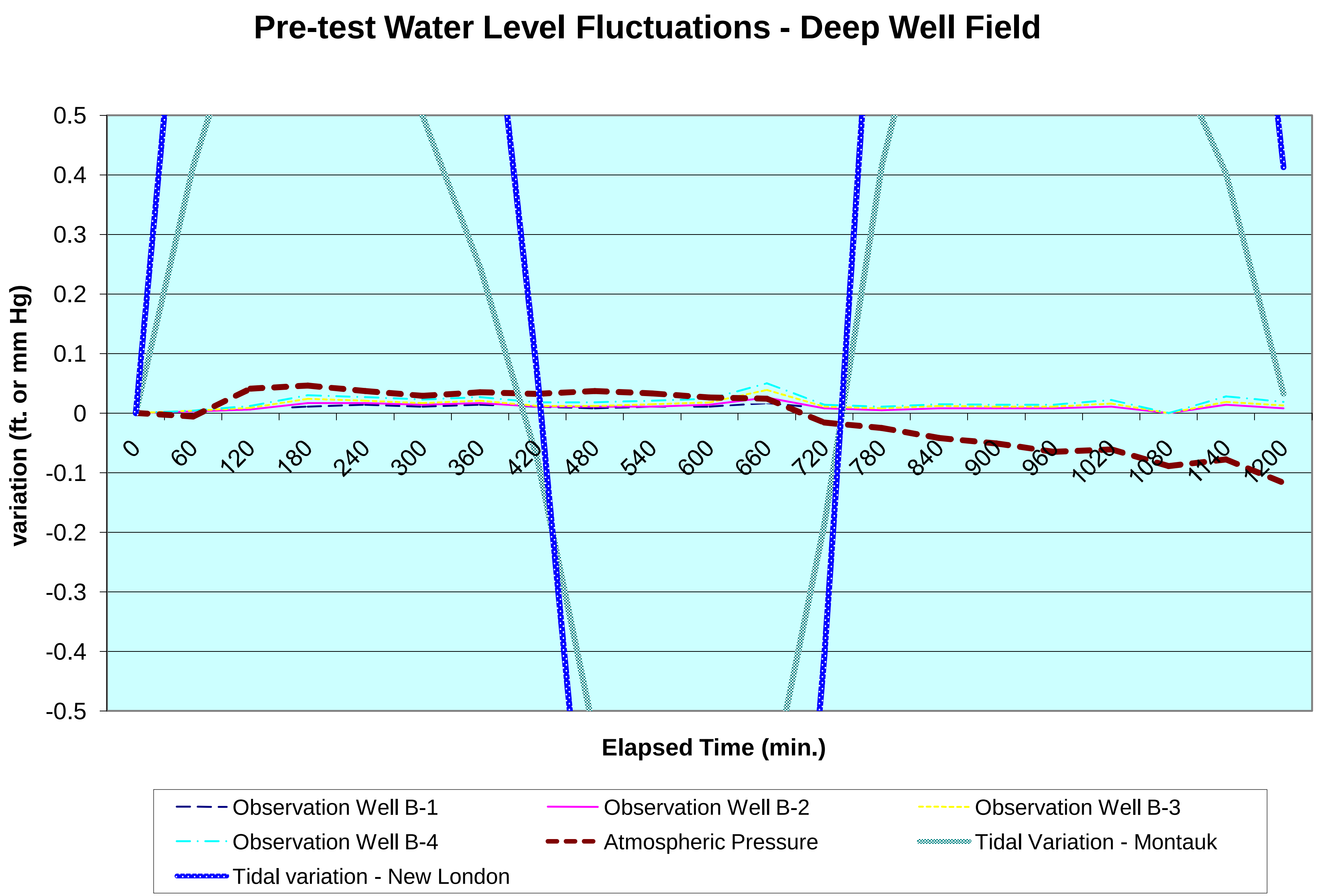
Pumping Test Specification

APPENDIX E:

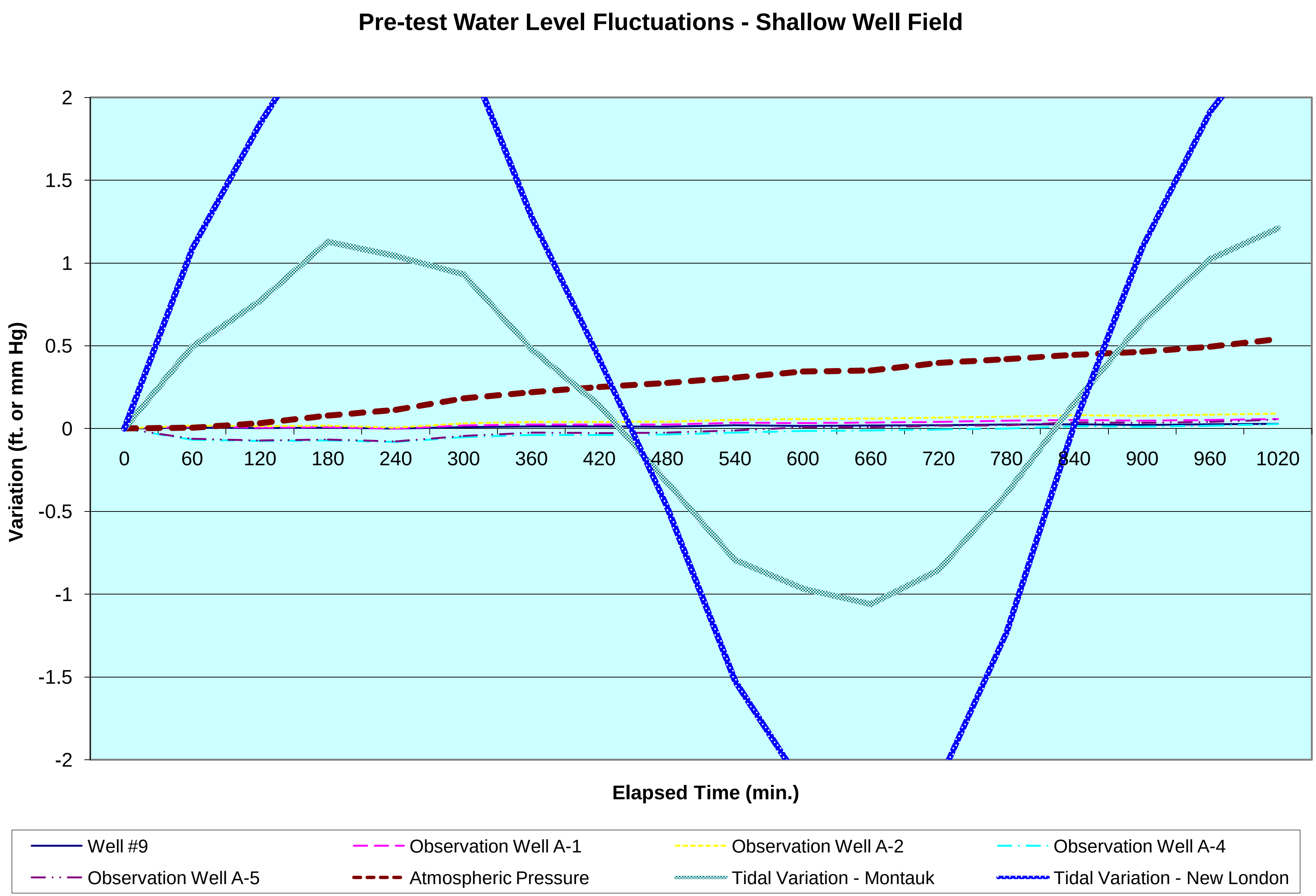
Observation Well Construction Diagrams and Boring Logs

APPENDIX F:

Pre-test Water Level Fluctuations



Pre-test Water Level Fluctuations - Deep Well Field
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
variation (ft. or mm Hg)
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1020
1080
1140
1200
Elapsed Time (min.)
Observation Well B-1
Observation Well B-2
Observation Well B-3
Observation Well B-4
Atmospheric Pressure
Tidal Variation - Montauk
Tidal variation - New London



Pre-test Water Level Fluctuations - Shallow Well Field
Variation (ft. or mm Hg)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1020
Elapsed Time (min.)
Well #9
Observation Well A-1
Observation Well A-2
Observation Well A-4
Observation Well A-5
Atmospheric Pressure
Tidal Variation - Montauk
Tidal Variation - New London

APPENDIX G:

Well Troll 8000 Data Logger Results (Conductivity, Drawdown and Temperature) for Observation Well B-6

APPENDIX H:

Boring Logs, Construction Diagrams and Well Acceptance Test Data Forms for Supply Wells 11-14

APPENDIX I:

General Schematic of Water Distribution System

APPENDIX J:

Water Supply Sampling Results - 1999